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A Summary of Current Program, 5/1/63;
and Preliminary Report of Progress
for 5/1/62 to 4/30/63

FOREST SERVICE

of the

UNITED STATES DEPARTMENT OF AGRICULTURE

This progress report is primarily a tool for use of Department scientists and administrators in program coordination, development and evaluation; and for use of advisory committees in program review and development of recommendations for future research programs. The summaries of research progress include some tentative results that have not been tested sufficiently to justify general release. Such findings, when adequately confirmed will be released promptly through established channels. Because of this, the report is not intended for publication and should not be referred to in literature citations. Copies are distributed only to members of Department staff, advisory committee members and others having a special interest in the development of public agricultural research programs.

This report also includes a list of publications reporting research results, issued between May 1, 1962, and April 30, 1963. This progress report was compiled in the Forest Service, U. S. Department of Agriculture, Washington 25, D. C.

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INTRODUCTION

Within the Federal government, the Department of Agriculture has primary responsibility for forestry research and, within the Department, the Forest Service is assigned the mission of planning and carrying out forestry research programs. These programs provide the technical basis for protecting, managing, and utilizing all of the renewable resources of the National Forests and National Grasslands administered by the Forest Service. They provide the technical forestry information needed by the Department of the Interior and other Federal agencies having custody of forest and range lands. And, they are concerned with the forestry problems of State and private land-owners and forest products industries.

As this report shows, the Department's program includes not only basic and applied research in forestry but also development of new products and techniques and dissemination of research results. The program is regularly reviewed to insure that balance and coordination are achieved. Goals for the next 10 years have been set forth in the National Forestry Research Program.

Research is performed at the national headquarters at Washington, D. C. ; at the Forest Products Laboratory, Madison, Wisconsin; at ten Regional Forest Experiment Stations which carry out projects at more than 70 other locations throughout the various States; and at the Institute of Tropical Forestry in Puerto Rico. In addition, there are two pioneering research units, one in forest mensuration and one in forest genetics. Most of the research is headquartered on or near the campus of a college or university and is organized into some 340 different projects staffed by 921 scientists.

The typical forestry research project is conducted in cooperation with others; usually the cooperator is a State Agricultural Experiment Station, a university, or a private industrial firm or trade association. More than 1,000 formal cooperative agreements are in effect.

To an increasing extent, progress in forestry is contingent upon progress in forestry research. In recent years, there have been numerous instances of the successful application of research results. A few examples follow:

New Industry Based on Low Grade White Pine. A new industry has been established in the Northeast to produce panellized lumber from low grade white pine. It was made possible through research which showed that sufficient clear material to warrant its use was available in this economically marginal grade. The research included an exploration of process costs, and set guidelines for a successful business operation. This development is highly important since hundreds of small mills in the area were closing down due to lack of markets for low grades of lumber which constituted about 80 percent of their production.

Big-game range restoration. Capacity of the winter range is the factor limiting production of deer and elk in most of the West, and many of these critical ranges are so depleted that artificial revegetation offers the only hope of restoration within a reasonable period. Research of the past few years has resulted in selection of adapted species, determination of seeding methods to allow satisfactory establishment, and development of a "browse seeder" to facilitate distribution and covering of shrub, grass, and forb seeds. Several thousand acres of State and Federal big-game range throughout the West have been satisfactorily rehabilitated during the last 2 or 3 years.

Range condition and trend. Ecological studies throughout the West have provided essential information on plant responses to environment. Patterns of vegetal change in relation to grazing use have been determined for many plant communities: shortgrass of the Northern and Central Plains, grass-shrub of the Southwest, salt-desert shrub and sagebrush-grass of the Inter-mountain, grasslands of the Western mountains, mountain meadows of the Pacific Northwest, and annual grasslands of California. This information has provided reliable standards for judging range condition and trend, and has materially assisted in the current appraisal and analysis of millions of acres of western rangeland by the Forest Service and other Federal agencies.

Fuelbreaks. Since 1958 ways of breaking up the solid stands of Southern California's brush into manageable fire protection units have been investigated. The key to success was found to be permanent conversion of strategic strips of brushland to a low growing ground cover. This eliminates the annual maintenance that made the older firebreak system intolerably costly. Research results have been rapidly adopted by Federal, State and local agencies. To date 435 miles of fuelbreaks totaling over 14,000 acres have been built. In 1962 the research was extended to Northern California to study the practicability of fuelbreaks for California's highly flammable timberlands.

Dwarfmistletoe Control. Silvicultural control of dwarfmistletoe on ponderosa pine in the West is becoming a reality now that research has shown that it can be done at low cost by combining dwarfmistletoe sanitation with thinning and pruning operations, on good sites, in younger age classes, and in the more lightly infested stands. Control programs are expanding rapidly even while research is still more precisely defining the conditions for further application to the hundreds of thousands of infested acres. To wait for complete analyses of economic relationships would be to lose control opportunities that will not occur again for a century or more; dwarfmistletoe infections multiply, infested areas enlarge, saplings become poles, and costs increase correspondingly from year to year.

More Water. Knowledge accumulated by research in forest soil and water management is being put to use on National Forest and municipal watersheds. Two National Forest watersheds, one in Arizona and one in Wyoming, are now using new techniques for the purpose of improving water yields. Plans are being prepared to make three additional watersheds in the snowpack zone operational during the coming year for improved water yield. Methods have been developed to the place where consideration is being given by the State of California and the Forest Service to plan for large-scale watershed management operations to improve water yield on one of the California rivers having headwaters in the Sierra Nevada. Furthermore, several municipalities are making plans to alter the management of their watershed lands from straight-out protection to improvement of water yield through timber harvest, without impairing water quality.

Better Seed from Better Trees. Results from forest genetics and forest tree improvement research are being put into practice at a rapidly accelerating rate. In 1963, there were 129 tree seed orchard plantations in 29 States, totaling over 7,000 acres. These seed orchards are dedicated to production of seed from improved or selected strains of forest trees. The seed orchard acreage has more than doubled since 1961. In addition, about 220 stands (totaling about 6,250 acres) in 37 States have been thinned down to the very best trees and are being managed intensively as seed production areas. About half of the seed orchards and seed production areas are in the South.

I. TIMBER MANAGEMENT RESEARCH

A. SILVICULTURE

Problem

The broad field of silviculture includes the problems of growing and tending forest trees and stands from seedlings to sawtimber. It deals with reproducing forests both naturally and artificially, with intensive cultural measures for improving the yield and quality of forest stands, with methods for evaluating and improving the productive capacity of forest soils, and with cutting methods required to perpetuate valuable species adapted to the site. Related to all of these problems are the basic physiological processes involved in tree growth.

Evaluation of soils and sites for the establishment, growth, and development of various tree species is basic to intelligent forest management. Knowledge of proper species or mixtures best adapted to particular sites is needed to guide regeneration programs, timber stand improvement operations, and stand conversion. The integration of fundamental and developmental research into systems for managing forest properties is the final phase of silvicultural research. Forest managers need to know how various prescriptions for better forest practices fit together into a unified management program. They also must know how other uses of the forest, such as water production, wildlife and domestic animal range, and recreation influence the management for timber production.

Program

A continuing program of research at all 10 Forest Experiment Stations and the Institute of Tropical Forestry in cooperation with various schools, State forestry groups, private industries, and other private forest landowners is conducted in this field of silviculture. Included is a comprehensive program of basic and applied research in seed production and seed handling, forest nursery practice, site preparation, direct seeding, and planting techniques for important timber species. Studies of natural regeneration and of the care and improvement of existing forests through pruning, thinning, weeding, and other stand improvement measures are carried on in all Experiment Stations.

A long-term program of research comparing different silvicultural systems in different forest types and stand conditions is conducted at many of the Stations to provide practical answers to forest managers. Often these studies are in cooperation with private timber companies who may provide forest land or purchase timber under contracts requiring special treatments and records.

The total Federal effort in silvicultural research in the United States amounts to about 200 man-years annually.

A program of research is also carried on under Public Law 480 in Brazil, Chile, Finland, India, Israel, Poland, and Spain.

Progress

1. Site Evaluation and Improvement

Evaluation of the productive capacity of the site is a very complex problem in several important timber types. In lodgepole pine stands the height-age relation, so widely used to develop site quality ratings for other tree species, was found to be inadequate under some stand conditions. In mathematical formulae relating height growth of lodgepole pine to various combinations of growth-controlling factors it was found that stand factors accounted for an exceptionally high percentage of the variation in height growth. The limitations of the height-age relation for expressing site quality for lodgepole pine were defined. Results point the way to other possible measures of site productivity and suggest a further course of investigation.

In southern Arkansas and northern Louisiana, significantly different height-over-age relationships have been found for loblolly pine growing on (1) loess soils, (2) well-aerated upland soils with good internal drainage and strong profile development, and (3) poorly aerated soils, with or without profile development, but with poor surface or internal drainage. Loess soils are uniformly good to superior for loblolly pine, and height growth can be expected to be rapid from an early age on past 50 years. Early height growth of trees on well-aerated soils is also an indicator of good later growth, though heights achieved on such soils will not be equal to that of trees on loess. Trees on poorly aerated zonal soils show a differential slowing down after age 30. The conventional site-index curves for loblolly pine (U.S. Department of Agriculture Miscellaneous Publication 50) usually give overestimates on these poorly aerated zonal soils when the height is measured in stands under 30 years of age and the readings extrapolated to age 50.

Over one-third of the Carolina Sandhills is in coarse, deep sands covered with scrub oak. The many successful old-field plantings of slash pine raised hopes that the scrub oak sites would be equally productive if cleared and planted to slash pine. This is not entirely true. A recent soil-site study made in cooperation with Duke University School of Forestry shows that the deep sand soils (10 feet or more to a clay layer) of prepared turkey oak sites are considerably poorer than the deep sand soils of old fields. However, plantations on soils with a clay layer within 10 feet of the surface or on soils with a 5- to 8-inch A₁ horizon, attained a height of 63 feet in 25 years. Lands with a site index of 30 feet at age 25 are sub-marginal sites for conversion to pine. On 40-foot sites the indicated yield at 20 years is about one-fourth cord per acre per year. On 50-foot sites, the average for deep sand old-field plantations, the yield is 1 cord per acre per year; obviously a much better investment opportunity. Potentially productive slash pine sites can be selected by examination of soil survey maps and soil profiles of proposed planting areas.

It is often necessary to determine site index for a species that is not present on a given area. Equations were developed at the Northeastern Station to express the relationships among site indices (base age of 75 years) of white ash, hard maple, yellow birch, and white birch. Given the site index of one species, the probable site indices for the other three species can be estimated from these equations.

Topography was determined to be the principal factor in site quality for paper birch in a study by the Lake States Station in northern Wisconsin. The silt-plus-clay content in the first 6 inches of soil and surface drainage also were found to have a major influence on growth of paper birch. Slope position, surface drainage, soil mottling, and depth to bedrock were other significant variables. Silvicultural prescriptions were presented for each site class, and yield data were determined for a limited range of ages and sites for which adequate stand data were available.

A greenhouse study conducted at the Central States Station to determine the tolerance of seedlings of several tree species to saturated soil showed a marked difference among the species in mortality and growth. Shumard oak and cherry-bark oak seedlings sustained heavy mortality, but some seedlings of all species survived continuously saturated soil conditions for 60 days. Four species, green ash, pumpkin ash, pin oak, and water tupelo grew significantly taller in saturated soil than in well-aerated soil on the greenhouse bench. Seventeen species were classified according to tolerance to water saturated soil conditions as follows: tolerant--green ash, pumpkin ash, water tupelo, and willow; intermediate--eastern cottonwood, boxelder, red maple, silver maple, pin oak, and sycamore; intolerant--shumard oak, cherrybark oak, American elm, willow oak, sweetgum, hackberry, and sugarberry. This study will be useful in explaining species composition of bottom-land sites and in selecting species for seeding or planting these areas.

Most methods available for measuring light under forest conditions are inadequate. In 1958, W. G. Dore briefly described a chemical method based upon the polymerization rate of anthracene (in benzene) into insoluble dianthracene, a process which depends upon the cumulative amount of light exposure. The method has been adapted to studies of regeneration on the Bartlett Experimental Forest in New Hampshire. Main advantages of the method are that it provides a measure of cumulative as opposed to instantaneous light; it is inexpensive; and it is adapted to simultaneous sampling of several locations.

To help establish reliable methods for evaluating the nutrient status of loblolly pine trees, a detailed study was made of the variation in nutrient content of the needles with season, age of needles, position in the crown, and soil. Percentages of N, Ca, and Mg were greater in the needles from the bottom part of the crown, whereas P and K percentages were greater in the upper part of the crown. Percentage of N in the needles increased during winter months after

the first growing season. Phosphorus percentage decreased each month for 1 year and then increased slightly. Calcium and magnesium percentages in general increased throughout the growth and maturation of the needles with the content approaching a constant value during winter months. The basic influence of the soil on some plots was reflected in a two-fold difference in Ca and a three-fold difference in Mg content of the mature needles. It appears that about one-half of the N, P, and K are translocated from the needles immediately before abscission. The results of this study indicate that the needles of the first growth whorl of the season at the top of the crown should be sampled in August and September of the first growing season for P, from December through March for K, Ca, and Mg, and from June through September of the second growing season for N.

Fundamental information on the nutrient requirements of trees leads to refined approaches to fertilization and site evaluation. A study conducted by scientists at the Northeastern Station in automatically irrigated sand cultures in a greenhouse showed that the uptake of three nutrients is closely related to supply. It also provided information on the minimum requirements of Virginia pine seedlings, deficiency symptoms for potassium and magnesium, and growth in relation to needle concentrations of potassium and magnesium. Comparisons of these results with those of an identical study with loblolly pine revealed no major differences between the two species in nutrient requirements.

Two years prior to fertilization, a 19-year-old slash pine plantation was thinned to 25 trees per acre for seed production purposes. Two commercial fertilizers (7-7-7 and 3-18-6) were broadcast by hand around single trees at rates of 20 and 40 pounds per tree in the spring. During the next 5 years, radial growth was 13 and 21 percent greater than controls for the two levels of 3-18-6 and 26 and 28 percent greater for 7-7-7. The increase in growth began the year after fertilization, peaked the second year, and declined to almost no increase in the fourth and fifth years.

The value of fertilization on a good site was shown on 1-year-old sycamore seedlings in Georgia. A moist but well-drained Piedmont river bottom site, disked prior to planting, was fertilized with the 27 combinations of 3 levels each of N, P, and K. First-year height growth showed a strong response to N, a smaller response to P, and a very slight response to K. Unfertilized seedlings grew 3.7 feet the first year compared with 6.6 feet for those seedlings fertilized at near optimum rates. The fertilized seedlings easily outgrew the competing vegetation.

2. Seeding and Planting

a. Seed production and handling

The seed crops of forest trees are irregular and unpredictable and relatively little is known about the mechanisms controlling the onset of flowering and the production of seed. Studies have shown that the application of fertilizer often increases the size of the seed crop. Because of the importance of nitrogen in the formation of new plant material, studies of nitrogen metabolism are receiving the initial emphasis in a fundamental study of seed crops at Durham, North Carolina. The organic compounds containing nitrogen are built up in the roots, utilizing the nitrogen absorbed from the soil, and are transported in the xylem sap. One of the first phases of the study was the determination of the major forms of nitrogen in the xylem sap. In the pines and other species glutamine was found to be the major nitrogen compound. By means of radioactive tracers some of the pathways of glutamine metabolism have been worked out. These processes will be studied in more detail in an attempt to find some shift which might presage the beginning of a flowering period.

A review of older stand density studies in the Lake States has provided interim guides for the establishment and management of seed production areas. The percentage of trees bearing cones and the number of cones per tree were inversely proportional to the residual basal area in a twice-thinned 51-year-old plantation of red pine. Maximum cone yield per acre should occur at about 80 square feet of basal area at the time of flower-bud differentiation. Maximum cone yield per tree should be greatest at densities lower than the 80-square-foot level observed in this study. Location of cones in the crown was only partially related to stand density with half to two-thirds of the cones occurring in the middle one-third of the crowns at densities of 80-154 square feet. The strong relationship of cone yields to residual stand densities provides a useful guide to spacing requirements for seed production areas, seed orchards, and regeneration cuts in red pine stands that should increase the frequency and amount of seed produced.

Seed production was greatest in shortleaf pine stands in Missouri thinned to 50 square feet of basal area per acre at age 30, and least in unthinned stands. Over a period of 5 years, about 800,000 more seeds per acre were produced in stands thinned to 50 square feet than in those thinned to 90 square feet. But the latter stands produced only 200,000 more seed per acre than unthinned stands. For maximum seed production in shortleaf pine stands of this age, basal area should be reduced to 50 square feet or less per acre to stimulate crown development.

In another study in Missouri, shortleaf pine trees fertilized with heavy applications of phosphorous or potassium in conjunction with a standard application of N, P, and K fertilizer produced nearly twice as many seeds as unfertilized trees.

The heavy application of phosphorus (180 lbs. per acre) resulted in the greatest seed production (54 lbs. per acre), whereas the unfertilized stand produced only 25 lbs. Potassium at the rate of 252 lbs. per acre resulted in a yield of 45.6 lbs. of seed.

Cones from fertilized slash pine trees are more popular fare for squirrels than cones from unfertilized trees. This apparent food preference was demonstrated on a seed-production study area near Olustee, Florida, where treated plots received 18 lbs. of 8-8-8 commercial fertilizer per tree. Squirrels took 11.7 percent of the cones on fertilized trees and only 1.3 percent on unfertilized trees. The total cone crop was two and one-half times as great on the fertilized trees.

With the increasing emphasis on producing seed in seed orchards, it is important that the limits of pollen flight and the quantity of pollen necessary for proper pollination be known. Two projects aimed at developing information on pollen behavior are under way in Finland under foreign research grants. In one, the time and quantity of pollen produced on selected trees is being related to weather conditions. In the other the flight of pollen tagged with radioisotopes is being measured. These two 5-year projects should give American tree-breeders basic information which can be applied to practical problems in this country.

In a study of methods for seed orchard establishment, the Central States Station found that yellow-poplar buds grafted in mid-July and early August, 3 to 6 weeks after scion height growth ended, made a higher percentage of successful unions with stock plants than did buds grafted at earlier or later dates. Cutting back stock tree tops 10 days after budding stimulated late summer scion growth, producing trees that may be suitable for field planting only 1 year after propagation. If these plants can now be made to flower early in life, the method will be helpful to nurserymen in growing quantities of seed from selected trees.

Yellow-poplar seed can be stored under stratification conditions for at least 3 years and improved during the process. In a study at the Central States Station, the number of seedlings produced increased progressively with the number of winters seed was stratified; several times as many seedlings were produced by seed stratified 3 years as by seed stratified 1 year.

Studies by the seed laboratory at Macon showed that germination of eastern white pine seed can be improved by treatment with citric or tartaric acid. Some improvement was observed from the acid treatments without stratification, but the most marked effect came after 30- and 60-day stratification periods. Up to 98 percent germination occurred after 17 days with stratified and treated seed. Acid treatment may make possible the maximum germination in the minimum time, thus reducing the risk of seed loss to predators and producing a more uniform stand in the nursery beds.

b. Planting and direct seeding

The Pacific Southwest Station conducted a study of indexes of physiological condition of stored ponderosa and Jeffrey pine seedlings in order to evaluate their vigor. The presence or absence of starch appeared to be a better indicator of the condition of the stock than water content or dehydrogenase activity. The starch in the stems and buds was depleted before that in the roots.

Many species of eucalyptus have been planted in Hawaii since the first large planting almost 100 years ago. Early plantings were for fuel, windbreaks, and soil protection. Recently interest was turned toward timber production for post, poles, and sawn products. Several species produce exceptionally high mean annual growth in volume (3,000 board feet per acre per year). A report by the Pacific Southwest Station summarizes information on preferred species, propagation, and wood uses that will be helpful in the reforestation program of Hawaii.

Transplant nursery stock is often required on the more severe planting sites because of its superior size and vigor. The cost of transplants, however, is approximately three times the cost of producing seedlings. To explore ways of obtaining larger seedlings and to eliminate the need for transplanting, the Lake States Station studied the effects of extended day-length on white pine, red pine, white spruce, and black spruce grown both in Wisconsin and Florida. The relatively short natural photoperiod in Florida caused dwarfing of the seedlings. However, extending the photoperiod to 20 hours permitted growth to continue throughout the 226-day growing season of Florida, and produced seedlings that at the end of 2 years were equal to or exceeded the standards for northern-grown transplants. Outplantings in the North survived as well as stock from local nurseries. Extended photoperiod in Wisconsin also increased the size of 2-year spruces. This pilot study indicates that growing northern species in southern latitudes is a feasible method of producing acceptable seedling stock for the adverse sites in one-half the time now required.

A soil moisture and growth study was made during the sixth and seventh growing seasons of a slash pine plantation in the Middle Coastal Plain of Georgia. Significant differences in diameter growth were found between 6 x 6, 8 x 8, and 15 x 15-foot spacings, but these differences were not associated with soil moisture, air temperature, or evaporation. Crown ratio, which increased with increased spacing, was believed to be the significant factor. Competition for light had begun in the fifth year in the close spacing, but competition for soil moisture had not yet occurred in the sixth or seventh season. In the Middle Coastal Plain of Georgia, soil moisture is apparently not a serious limiting factor in plantations of this age even at close spacings, although it should become important as the stand develops.

Some basic facts concerning the mechanism of the action of mulch around planted trees on bare soil were revealed in a study in the tention zone in eastern Texas.

Mulched loblolly pine seedlings grew faster than unmulched because of more adequate supplies of available soil moisture. Mulch, did not, however, reduce net soil moisture depletion. The better moisture supply under mulch resulted almost entirely from superior accretion, due probably to higher surface infiltration rates. If the mulch reduced evaporation from the soil surface, this effect was obscured by other moisture losses.

In east Texas, the periodic root development of loblolly pine seedlings was studied by the Stephen F. Austin State College cooperatively with the Southern Forest Experiment Station. One-year-old nursery-grown seedlings were planted at 2-week intervals from November 16 to March 22. Subsequently, a total of 400 randomly selected seedlings from all planting dates were excavated at 2-week intervals beginning November 30 and ending June 14. Roots of seedlings planted in November began growth as early as February; lateral roots close to the surface were the first to grow, followed by the deeper laterals and then the main roots. It was concluded that temperature controlled root regeneration and growth from November to February, while from March to June soil moisture became the most important factor. Early planting is advisable where late spring or early summer droughts may be expected.

Cottonwoods (Populus deltoides Bartr.) of selected clones grown on a suitable site in the Mississippi Delta reached an average height of 22 feet in two growing seasons. The tallest tree was 30 feet tall and 4.8 inches in d.b.h. The best selections of native cottonwood outgrew the best poplar hybrids from Europe, but it is too early to tell which clones will be superior in other attributes such as pest resistance.

Direct seeding research for the East is concentrated at the Alexandria, Louisiana project, and some of their results have application nationwide. They are currently perfecting a method of seed treatment that promises to be faster, less expensive, and much safer to the men. The repellents and binder are mixed and applied in liquid form. This permits a continuous, once-through process and eliminates the chemical dust hazard.

The mycorrhizal association has been established as essential to forest trees under natural conditions. To better understand this relationship, particularly in the pines, a global program has been started under the foreign research program. A project in India is aimed at finding out what fungi are associated with the pines. The information will guide foresters in this country in establishing exotic trees for tree-improvement purposes. If a specific association is necessary, the proper inoculation could be made. Projects in Poland and Finland are aimed at a better understanding of mycorrhizae under cold-climate conditions. These will provide basic information to guide planting and nursery practice in northern United States and Alaska.

3. Natural Regeneration

Three frequently-used methods of harvesting old-growth stands of Engelmann spruce and subalpine fir were studied in Colorado to identify the one that produced the best spruce regeneration and the least damage to the residual stands. Well distributed abundant reproduction was established following removal of 60 percent of the merchantable volumes by: (1) alternate clear-strip cutting, (2) circular patch clear cutting, and (3) individual tree selection cutting. Growth of the residual stands was not stimulated by any of the cutting methods; mean annual net increment was related to reserve volume. Mortality, especially windfall, was heavy but not equal in all residual stands. Alternate clear-strip cutting is recommended because of the more abundant and better distributed reproduction and smaller loss from windthrow.

Seeds stored in serotinous cones can be an important factor in regeneration, particularly after a fire. The Lake States Station conducted a study of the number of viable seeds stored in closed cones of jack pine and found from 226,000 per acre for 40-year-old unthinned timber to 759,000 for thinned timber of this age. Plantations only 9 to 13 years old had more seed (477,000) than 70- to 80-year-old overmature stands (381,000). These amounts (1.7 to 5.8 lbs. per acre) are more than enough under favorable conditions to regenerate stands destroyed by fire.

Girdling of Douglas-fir seedlings by high temperatures at the soil surface is a major deterrent to establishment of Douglas-fir on many sites. From the anatomical standpoint, the existence of relatively heat-resistant tissues has been postulated as the cause of differences in apparent heat tolerance of the seedlings. No evidence was found for relatively more resistant tissues from a study of the anatomy of seedlings killed by surface heat under controlled conditions. The threshold beyond which damage is lethal was ascertained anatomically to be when injury proceeds inward beyond the pericycle. The finding that the cambium is killed upward and not downward beyond the heat injury of the remainder of the stem is evidence that the transpiration stream is not a major factor in preventing heat damage. This study is part of a general field and laboratory investigation of heat injury which will give valuable guides to regenerating Douglas-fir.

4. Silvicultural Systems

Juniper is the most widely distributed tree species in the Southwest and is an important local source of fuelwood and fence posts. In a study by the Rocky Mountain Station it was found that over a 20-year period the net annual increment of a stand of Utah juniper in central Arizona was only 2.9 cubic feet or approximately one 7-foot fence post per acre. Forest practices other than protection are not promising from the standpoint of timber alone.

Information on wood quality and weight is needed by both forest industries and forest managers. Wood users are interested in specific gravity because it is related to strength properties and fiber yield. Forest managers need reliable methods for converting forest inventories and yield estimates from a volume to a weight basis. A nondestructive method of determining specific gravity of standing trees, developed largely by the Forest Products Laboratory, has proven reliable for lodgepole pine in a study by the Intermountain Station. Specific gravity at breast height, calculated by the increment core method, gives a satisfactory estimate of average tree specific gravity, expressed by means of a regression equation. The study also showed that specific gravity decreases noticeably from stump height up to 20 feet, but changes little above that.

Studies in the physiology of wood formation at a new pioneering research unit of the Lake States Station point out the importance of auxin in the wood formation process. Five-year-old red pine seedlings were subjected to artificial drought periods of varying duration during the growing season. A single drought period resulted in formation of a false growth ring, whereas two drought periods produced two false rings. Formation of the false rings was correlated with decreased needle elongation and decreased auxin synthesis. Renewal of normal tracheid formation following the drought could be prevented by inhibiting renewed needle elongation and the increased auxin synthesis that accompanies elongation. It was concluded that the drought effect acted directly on the growth of the terminal meristems and only indirectly on tracheid diameter through the intermediate action of auxin. The studies also included the effect of photoperiod on tracheid diameter by independently exposing the buds and needles to different day-lengths. The studies showed that the effect of photoperiod is indirect and is associated with auxin production and distribution from the terminal meristems.

Field experience and new research results both pointed to the need for revision of an earlier guide for managing upland central hardwoods on the National Forests of the North Central Region. A new guide published by the Central States Station makes several notable changes from previous management recommendations: It recognizes the need to use even-aged silviculture for reproducing and growing central hardwoods. It recognizes site quality as the basis for selecting the species to favor and the intensity of management to apply. It recognizes the necessity for regular thinnings to maintain rapid growth on the size class selected as the final crop. The guide contains new descriptions and tables for classifying and identifying different degrees of site quality. It describes new concepts of optimum stocking for central hardwoods and tells how to measure and control stand densities. And it contains a key to silvicultural prescriptions for common stand conditions encountered in the Central States. Although prepared specifically for use on the National Forests, principles and procedures in the guide are equally applicable to State forests, industrial holdings and farm woodlands. Use of the guide will result in full utilization of a forest site in the production of high-quality timber under the shortest rotation feasible.

Sawlog quality is customarily appraised on the basis of individual trees. The Southeastern Station made a study of quality based on stand factors. A series of 47 uncut, 1/4-acre permanent plots of insect- and disease-free, even-aged, pure loblolly pine in Georgia, South Carolina, and Virginia were used in assessing the effects of age, site index, and density on sawlog quality. Plot ages ranged from 25 to 93 years, site indices from 52 to 104 feet, and stand densities from 102 to 179 square feet of basal area per acre of stems 0.6 d.b.h. and larger. The index of sawlog quality was "K"/MBF where "K" equals the number of overgrown knots, plus the sum of diameters of sound, exposed knots, plus twice the sum of diameters of unsound knots. The best fit of 2 stepwise regression analyses resulted in the following equation:

$$\text{Log ("K"/MBF)} = 3.313940 - .013522 (\text{Age}) - .000185 (\text{Age} \times \text{Site})$$

Approximately 89 percent of the variation about the mean was accounted for by this expression. This research opens the possibility of using quality ratings for entire even-aged stands rather than for individual trees, and of predicting future changes in stand quality.

5. Stand Improvement

a. Thinning

Many studies are underway to determine the relationship of stand density to growth rate and quality of managed stands of important timber species. The results of several of these studies became available in 1962. Two stand-density experiments in pure stands of red pine in Minnesota, one in 80-year red pine, and the other in 40-year red pine, have been followed for 10 years. A third experiment, in 50-year red pine, has been followed for 5 years. Basal area growth was only slightly influenced by stand densities ranging from 60 to 140 square feet of basal area per acre. Total height growth also was about the same throughout this range of stand densities. Total cubic-foot volume and cordwood growth increased as density increased, with the increases most pronounced in the young stands. Diameter growth of dominant and codominant trees was twice as much at 60 square feet of basal area as at 140 square feet. If the objective of managing such red pine stands is a large volume of wood in a large number of relatively slow growing trees, thinning is not necessary. If the desired products must come from larger trees with faster diameter growth rate and wider annual rings, thinning is necessary, even with a slight reduction in total volume growth.

Most Lake States plantation species are resistant to snow damage, but an exceptionally heavy wet snow may result in damage to dense stands soon after they have been thinned. In April 1961 a 10-inch wet snow, accompanied by gusty winds, caused serious damage in jack pine plantations thinned the previous year. Frequency and type of damage was related to residual stand density and

method of cutting. The percent of trees damaged decreased as basal area increased from 30 to 120 square feet in compartments thinned primarily from below. Roughly twice as many trees were damaged in row-thinned compartments at comparable levels of basal area. Red pine with identical treatments was uninjured during the same storm indicating that one method and intensity of thinning will not be equally satisfactory for all species. This study also suggests the desirability of wider initial spacings in jack pine plantations.

Decay caused by fungi that enter through wounds on residual trees made during thinning is another factor that must be considered in thinning forest stands. Recent studies made 6 to 8 years after thinning in 37- and 55-year-old Douglas-fir and western hemlock indicate that little serious decay occurred in Douglas-fir; whereas in hemlock 33 percent of all residual stems were injured, and 61 percent of the injured trees contained some decay. The occurrence of decay increased with increase in size of wound and was greater in basal wounds than in wounds higher on the tree trunk. Stereum sanguinolentum and Fomes annosus were the principal fungi causing decay in Douglas-fir and hemlock, respectively. Implications are that logging injury decay will be minor within rotation ages planned for Douglas-fir. However, it is apparent that special care will be necessary in thinning hemlock, and that short rotations may be necessary to minimize decay losses in thinned stands.

A study in pole-sized ponderosa and Jeffrey pine in California showed that all types of low vegetation retarded the growth of the trees, and that grasses had a greater effect than the broad-leaved plants. The cost of controlling this low vegetation with 2, 4-D and Dalapon are too high to be practical for large-scale use at present. Until economical controls are devised, it might be necessary to keep the stands dense enough to keep low vegetation in check.

b. Pruning

Young Douglas-fir trees must be relied upon more and more as a source of raw material for the plywood industry as the supply of old-growth trees diminishes. A study of the veneer grade yield from pruned Douglas-fir in the Pacific Northwest shows that an average of 4 inches of diameter growth was needed before grade A veneer could be recovered from 4-foot blocks. This was equivalent to 17 years' growth in a thinned 38-year-old stand on an average site. This much growth was needed to completely occlude knots and overcome losses due to stem taper and other normal stem irregularities.

c. Herbicides for killing unwanted woody plants

Two studies conducted in central Louisiana indicate that costs of killing unwanted upland hardwoods by tree injection can be reduced by using undiluted 2, 4-D amine. Wider spacing between injections, less frequent refilling of the tool, and use

of a substantially cheaper chemical offer savings over the standard treatment of injecting diluted 2, 4, 5-T ester into incisions 1/2 to 1 inch apart. Continued investigations are needed to define the best combination of dosage and injector spacing. Injection of low-cost herbicides at intervals of 3 inches or wider promises new savings in the fight against low-grade hardwoods.

Another study in Louisiana provided new and more complete information on the elements required for good kill of blackjack oak when 2, 4, 5-T ester is applied as a basal trunk spray. Among several methods of applying propylene glycol butyl ether ester of 2, 4, 5-T (8 pounds acid equivalent in diesel oil) spraying the lower 12 inches of the stem and the surrounding 4 inches of soil surface produced the highest crown kills and least sprouting. Crown kills were low when spraying was confined to the soil alone or to a 12-inch band on the trunk starting 4 inches above the root collar.

Diluted 2, 4, 5-T amines (8 pounds ahg) were inferior to 2, 4, 5-T esters when applied in complete frills at the bases of trees of 11 species in the Northeast. Although 2, 4, 5-T esters are satisfactory for most trees, ammonium sulfamate crystals in notches were found to be more effective than 2, 4, 5-T on trees with infolded bark or other deformities that prevent making complete frills.

Rhododendron is a severe and hard-to-eradicate competitor of tree regeneration in the Appalachian Mountains. Four methods of control were studied on the Fernow Experimental Forest: no treatment; stem-cutting, stem-cutting and stump-spraying with 20-pound ahg 2, 4, 5-T in diesel oil, and basal spraying with the same mixture. Both methods in which chemicals were used were highly effective. Basal spraying was less expensive than cutting plus stump spraying but both methods are considered too expensive for large-scale use. However, they can be used to eliminate scattered clumps of rhododendron to keep it from spreading and to eliminate it on special-use areas where cost is not a limiting factor.

A key to restocking of conifers on recently cutover forest land in coastal Oregon and Washington is the elimination of competition from red alder. Recent studies have shown that alder can be readily killed by basal treatments with a 1:1 mixture of 2, 4-D and 2, 4, 5-T esters in diesel oil during the growing season. The use of these basal treatments on single trees or small groups provide an important supplement to aerial spray techniques used on large areas.

Salmonberry is another serious competitor to conifer reproduction in coastal forests of the Pacific Northwest. In a recent study on methods of reducing this competition, plants of this species were basally treated with phenoxy herbicides in diesel oil during the dormant season and at bud bursting time in April. January applications gave generally poorer results than those in March and April. March and April applications produced 100 percent defoliation and kill

for all treatments, with only erratic exceptions. Diesel oil alone gave effective control only in April.

A summary of the results of research on the use of herbicides for controlling unwanted shrubs and trees in California and adjacent areas contains recommendations on formulations and amounts of herbicides to use for controlling 31 different shrub and tree species.

6. Animal Damage

The preference of porcupines for dominant and codominant small poles may lead to serious losses in thinned ponderosa pine stands. A survey in the Black Hills showed that dominant and codominant ponderosa pines, 6 to 8 inches in diameter, were the trees most frequently attacked by porcupines. These also are the type of trees selected for leaving in thinning operations. Thinning will accentuate the need for control measures.

To maximize the effectiveness of TMTD as a rabbit repellent, the chemical should be sprayed on the seedling trees when the temperature is high. A study in Washington showed that much of the chemical was lost from the seedlings when it was sprayed on during cold weather. The chemical is stable on the foliage and is not broken down by biological action. Further research is needed to find the most effective dosage to repel rabbits.

In the Southwest both TMTD and ZAC reduced the incidence of browsing by deer from 56 percent to 8 or 9 percent. When applied as a 10-percent spray, the two chemicals were equally effective, but for only one growing season. However, the seedlings grew rapidly with the protection and would soon be out of reach of the deer.

7. Windbreaks

In the windbreak establishment program of the Great Plains it is important to be able to predict the growth rate of new or planned plantings. The Rocky Mountain Station published height curves for ponderosa pine in Nebraska windbreaks that can be used to predict future heights up to 22 years after planting and to rate site productivity. These curves will be a valuable tool in windbreak establishment in this area.

In the Northern Great Plains many shelterbelts have been impaired by sod competition. To determine the effects of renewed cultivation, two sod-bound shelterbelts were given various degrees of cultivation. After two years all species were found to have benefited in height growth from all cultivation treatments as compared to uncultivated plots. Growth in diameter and crown spread were also generally better. Green ash, boxelder, and American elm showed the greatest increase in growth and caragana and Rocky Mountain juniper, the least.

The results of early Forest Service studies of the influence of windbreaks on Great Plains field environment and crops, conducted mainly in the thirties, were brought together and published as a USDA Production Research Report.

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B. FOREST MENSURATION

Problem

Intensive management of the forest types of the United States requires improved measurements of timber tree volumes and more reliable predictions of future growth, yield, and quality of forest products. Productivity of forests both in quality and quantity varies markedly according to stand density as well as by site quality, tree age, and species composition. Optimum stand conditions for particular management objectives need to be determined for the many combinations of timber types, sites, and conditions found in American forests. Important forest regulation problems involving levels of growing stock, cutting budgets and rotation lengths must be solved to guide wise management of large timber holdings.

Program

A continuing program of studies is conducted at all the Stations, often in cooperation with industries, other private landowners, State forestry agencies, and forestry schools. Special attention is being given to research in the growth and yield of managed forests, juvenile forest stands, and forest plantations. Research is also concerned with mathematical techniques and forestry measurement tools that will make for greater precision and efficiency in practical forest management operations and in forest research. A pioneering research unit in Berkeley, California, established in 1961 is studying basic mensurational problems. Nationwide, approximately 6 man-years of Federal scientific effort is performed in formal mensuration research projects, and a like amount is devoted to related growth and yield studies in silviculture projects.

Progress

1. Growth and Yield of Forest Trees and Stands

Research is resulting in progressive refinements in the use of the height-age relationship used to designate site index or site quality. One of the most accurate techniques for developing height-over-age curves is actually sectioning dominant trees and determining exact ages for various heights during the trees' lives. But studies showed that height growth of individual trees does not necessarily represent height growth of stands. Shifts in relative tree height were demonstrated to be a major reason for differences between individual tree height growth and stand height growth in a study of lodgepole pine in the Pacific Northwest. Special techniques have now been worked out to derive stand height and growth from individual tree height growth that is free from error caused by shifts in relative tree height.

In the Southeast, research has shown that the shape of the curve representing the height-age relationship for yellow-poplar in the Appalachians is not applicable in the Piedmont. Accordingly, separate families of site index curves were developed for the two regions. Both sets of curves were compared with McCarthy's USDA Technical Bulletin 356 on growth and yield of yellow-poplar. In general, the growth and yield bulletin underestimates site index in the younger ages and overestimates site index in the older ages when applied to mountain stands. These new curves will increase the accuracy of site index determinations in the mountains.

Mensurational tools for correct estimation of site quality are still lacking for many important hardwood species. Using tree stem analysis, site index curves were developed for white ash, sugar maple, yellow birch, and white birch growing on acid glacial till in the Green Mountains. The curves will be useful in research work and, where even-aged stands occur, in commercial forest management.

In the mixed conifer forests of southwestern Oregon, the relative growth rate of the three most important species--Douglas-fir, sugar pine, and ponderosa pine--varies from area to area. In a study comparing site index in the upper South Umpqua drainage, the site index for sugar pine and ponderosa pine was found to be correlated with Douglas-fir site index and elevation. Relative indexes were determined for elevations from 1,500 feet to 5,500 feet. Until better information is available, the site index relationships reported are useful as an aid in making preliminary recommendations regarding choice of species to grow on different physiographic sites in this area.

Methods of expressing timber stand density are continually sought to improve our measurement and prediction of forest growth. The Southeastern Station used 10-year data from a loblolly pine growth study to compare four expressions of stand density. Stahelin's percent of full stocking, total basal area, Reineke's stand density index, and initial merchantable cubic-foot volume were tested as expressions of density in combination with age and site in regression analyses of cubic-foot growth. Essentially the same amount of variation ($R^2 = 77$ to 79 percent) in annual cubic-foot growth was explained by each expression in combination with age, site, and certain of their significant interactions from data involving repeat measurements of stands throughout a wide range of initial age, site, and stand density. It is concluded that the choice among the variates expressing stand density is primarily at the discretion of the investigator. However, ease of computation and application and the advantages occurring from the use of a direct measure rather than an index suggest the use of basal area unless bio-economic analyses are desired.

The Southeastern Station developed an expression of board-foot growth for even-aged loblolly pine stands based on age, site, and stand density from 10-year permanent sample plot data from Georgia, Virginia, and South Carolina. Periodic annual board-foot growth was related to these variables as follows:

$$\begin{aligned} \text{Board-foot growth} = & 866.80 + .37917\left(\frac{10,000}{\text{Age}}\right) - 23.77740 (\text{Site}) \\ & + .14207(\text{Site})^2 - 17.08437 (\text{Basal Area}) \\ & + .37445(\text{Site} \times \text{Basal Area}) - .00071 \\ & \quad \sqrt{\text{Site} \times (\text{Basal Area})^2} \\ & R^2 = .794 \end{aligned}$$

It is concluded that the relations between board-foot growth and the independent variates confirm the adequacy of the study design and analysis model synthesized for this study. Comparisons of this study with other studies point out that these analyses provide the first clear indication of the importance of the site-stand

density interaction in board-foot growth of loblolly pine. Values presented in this paper provide stocking standards for loblolly pine growth in uniformly spaced, insect- and disease-free stands. Growth prediction values must be scaled down for extensive holdings because of heterogeneity of stocking, clustering, voids, and nonproducing areas.

Growth data for managed stands are urgently needed for all forest types, but they can be developed only for species that have been under management for many years. Growth and yield tables for managed stands of red pine for site indexes ranging from 45 to 60, for stand ages ranging from 25 to 165 years, and for stand densities ranging from 60 to 180 square feet of basal area per acre were produced by the Lake States Station. Techniques used in the preparation of the tables were also discussed. Several factors--for example, numbers of trees per acre, intensity of thinning, and crown thinning versus low thinning--have little effect on per-acre volume growth rates in managed red pine stands. On better quality land, managed red pine stands are capable of producing up to 1.8 cords per acre per year periodic annual increment, and up to 1.3 cords mean annual increment. These tables will be valuable in guiding the management of red pine for the production of a wide range of products.

New yield tables and charts for even-aged stands of western hemlock are presented in a USDA Technical Bulletin. For stands over 40 percent hemlock, the new tables replace Technical Bulletin 544 which was originally intended to represent all mixtures of Sitka spruce and western hemlock. The basic data were collected over the entire coastal fog-belt range of the species, from southern Oregon to southeastern Alaska. A single set of site curves serves for all regions, but three sets of regional tables are used to present volume yields, one each for Oregon-Washington, British Columbia, and Alaska. The new tables will facilitate yield predictions for hemlock stands and permit improved scheduling of forestry operations.

A study by the Rocky Mountain Station produced a method for predicting forest growth when yield tables or data from permanent sample plots are not available, as is true in the Black Hills of South Dakota and Wyoming. Single sets of measurements from temporary plots were used to reconstruct the forest stands 10 and 20 years previously. From these data, regression analyses produced predicting equations for future 10- and 20-year values of average diameters, basal area, and cubic volume.

White pine has long been a preferred species for planting in the Appalachian mountains: from 1952 to 1960, for example, about 20 million seedlings were planted in the 15 western counties of North Carolina. To meet the need for growth and yield information for these plantations, the Southeastern Station has developed site index curves, cubic-foot and board-foot volume tables and yield tables, cubic-foot to board-foot converting factors, and tables for predicting

average stand diameters. These tables are based on tree age, initial spacing, and site index.

The principal forest industries within the longleaf and slash pine belt are now at the stage where their holdings are approaching full production. Acreage in slash plantations is high, and one of their main needs is for plantation growth and yield data. A publication by the Southeastern Station is a summary of the work in the entire field of slash pine plantation growth and yields; it draws heavily upon the research at our Cordele, Georgia, unit. Height and diameter growth results from the George Walton Experimental Forest installations are summarized. In addition, slash pine cubic- and board-foot yield data from studies in South Carolina, Georgia, Florida, and Alabama are summarized, discussed, and interpreted. The paper provides prediction mechanisms for forest management decisions which have not previously been assembled and interpreted in toto.

Studies were made of yield and growth data for six planted conifer species in relation to initial spacing and stocking. The following points were developed:

1. Yield from unthinned stands of the six species examined--slash pine, loblolly pine, longleaf pine, eastern white pine, red pine, and Douglas-fir--show a remarkable similarity in relation to spacing. At ages 20 to 35 the cubic volume yield of 200 trees per acre is better than half the yield from 1,000, and the yield from 600 trees is 90 to 98 percent of the 1,000 tree yield.
2. A relatively strong statistical interaction of site quality and stand density is evident, indicating that the stand density for best growth is lower on poor sites than on good sites.
3. The age-density interaction appears to be relatively weak, especially beyond age 15.
4. Mean annual increment appears to culminate from 18 to 30 years of age for most species.
5. During the 15- to 20-year period, growth on slash pine stockings beyond 400 trees per acre is generally less than 3 percent; during the 20- to 25-year period, growth on stockings beyond 400 trees per acre is negligible.
6. Based on average planting costs, there are no positive earnings for slash pine during the 15- to 20-year growth period on stockings beyond 800 trees per acre.

Foresters often use "q", the average quotient between numbers of trees in successive 2-inch d.b.h. classes, as a convenient means for describing diameter distributions and stand structure in uneven-aged stands. To facilitate the calculation of "q", the Northeastern Station developed a least-squares method that is as accurate, simpler, and faster than the conventional graphic methods previously used.

2. Forest Measurements

Wedge prisms are widely used as the rangefinding device in point sample cruising. However, for accurate results, their power (prism diopters) should be suited to stand conditions. For general use in northern Rocky Mountain forests, the prism having a basal area factor of 25 (4.79 diopters) appeared to be most useful. For stands of small diameter and good visibility such as lodgepole pine in Montana, the 10x prism was suitable and perhaps more efficient than the 25x prism. For well-stocked, large sawtimber prisms of even larger factors than 25x may be desirable. Careful checking of marginal trees with a tape was found necessary to avoid bias. Seventy percent of the trees considered marginal were actually within their limiting distance. To obtain equally precise estimates of basal area, fewer plots and fewer trees per plot were indicated for point samples than for the 1/5- to 1/50-acre concentric fixed-area plots.

The surface area of tree crowns is an important factor in determining growth, stand density, and tree condition. The Central States Station developed a formula which shows that for cone-shaped crowns, the surface area is about 1.65 times the product of length and diameter; for paraboloid-shaped crowns, it is about 2.16 times the product. This formula will greatly facilitate quick determination of crown surface areas.

3. Management Inventories and Plans

An analysis of the Clark Fork Unit in western Montana takes a new look at the timber needs, quality of existing forests, and the economics of management. The timber we are growing is poorer than the timber we are cutting. It may be possible to increase the yield to twice the present cut by dealing more intensively with problems of understocking, overstocking, disease control, better regulation and more effective stand regeneration. The study shows the nature of a program that would be needed to complete a large backlog of work in such silvicultural measures as pruning, planting, cleaning, and thinning. Thinning makes up nearly half of the program.

A report from the Intermountain Forest and Range Experiment Station considers the problems of inventory procedures and statistics from the standpoint of developing a data structure for management controls. The gathering of timber

inventory and management data can best be done in two stages. The first stage would be a plot survey to give a general picture of the forest, including the volume of wood present. It would also provide (1) the data needed for calculating cutting budgets, (2) the necessary data for estimating the nature and cost of needed management and priorities of action, (3) a basis for classifying stands in the second-stage survey. The second-stage survey is a means of locating and classifying stands in terms that reflect the management situation, thus providing the basis for direct action. This report describes the job of both the first and second stage surveys.

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C. FOREST GENETICS

Problem

The development of artificial reforestation programs in the United States has set the stage for a tree improvement program of major proportions. Basic facts are needed concerning natural variation in forest trees and the heritability of characteristics that have biological or economic value. Strains or hybrids of timber trees having rapid growth, high quality, and superior pest resistance must be developed as soon as feasible.

Program

A continuing, long-time program of basic and applied research involving the whole field of genetics as applied to forest trees, from cytogenetics to phenotypic selection and progeny testing, is under way. The program involves the study of variability within species with respect to growth rate, form, and adaptability to environment as a basis for superior tree selection. It is concerned with the heritability of characters such as disease and insect resistance, drought and cold resistance, wood quality factors, vigor, and other important morphological, physiological, and anatomical characters. Other aspects of the project include the investigation of crossability of various species, aimed breeding for specific characters, radiation-induced mutations, and factors affecting fertilization and flower induction. Basic genetic processes are investigated through cytogenetic studies of tree species. Also included is research on the identification, classification and distribution of species and hybrids of forest trees.

The program is carried on principally at three Institutes of Forest Genetics located at Placerville, California; Gulfport, Mississippi; and Rhinelander, Wisconsin; with additional work in Oregon, Idaho, Illinois, Vermont, Pennsylvania, Georgia, Florida, and Louisiana, involving cooperative research with numerous State agencies, private foundations, universities, and forest industries. In addition, research grants for basic research in genetics under the provisions of Public Law 480 are in force in Finland, Israel, India, Chile, and Brazil. The annual Federal scientific effort directed to this research by the Forest Service is about 27 man-years.

Progress

1. Variation

Two early Forest Service provenance studies in the Northwest, one 30 years old and the other 45 years old, show convincingly the geographic variation in growth rate and other characteristics of ponderosa pine. Growth rate was found to increase from east to west in the range of the species. Also the inherent growth rates were related to springtime temperatures and yearly rainfall patterns of the seed source. Bole taper, frost resistance, resistance to animal damage, time of beginning and ending of seasonal growth, and rate of seasonal growth were shown to be related to seed source, also. On the basis of this information tree breeders will know what geographic areas are likely to have trees with characteristics useful in the improvement of ponderosa pine.

Scotch pine, a desirable exotic for timber and Christmas trees, exhibits wide variation among provenances in growth characteristics. Evaluation of an 18-year-old planting of 43 seedlots in Herkimer County, New York, indicated that growth was slow for the extremely northern provenances and high-elevation sources. The southern provenances were characterized by greener fall needle color, greater volume production, and somewhat fewer well-formed trees. The results provide guidelines for choosing appropriate seed sources.

Douglas-fir seedlings frequently are damaged by late spring frosts, which kill the new growth. The time of bud-bursting, or flushing, was found to be extremely variable and under strong genetic control in a study in Oregon. Consequently time of flushing should be one of the selection criteria for trees selected as superior parents.

The specific gravity of slash pine wood is a highly variable and important characteristic. This variability is a result the interaction of the tree's genetic make-up and the environment in which the tree grows. In a study aimed at determining the feasibility of selecting slash pine for high specific gravity in the Southeast, it was determined that specific gravity was under strong genetic control. However, the

percent of summerwood was much less strongly controlled. Modest gains in average specific gravity can be made by selecting parent trees for specific gravity.

The interaction between a tree's hereditary potential and its environment also determines how it responds to day length. Loblolly and shortleaf pine seedlings from southern sources made more height growth under short days than did those from northern sources, which have become adapted to longer days. These findings help explain some of the variation in growth among trees from various sources.

Further evidence for adaptation to local environment is shown in white pine plantings in Georgia and North Carolina and southern pine plantings southwide. After 3 years the height growth was inversely related, with a high correlation coefficient, to the latitude of the seed source. In these southern plantations, trees of northern sources were much shorter than those from the southern part of the range of white pine.

Fifth-year results of the Southwide Seed Source Study show significant relationships between source of seed and growth of the trees. A correlation coefficient of 0.92 was found for the height of loblolly pines planted in Maryland and the latitude of the seed source. A negative correlation existed for plantations in Mississippi. The incidence of fusiform rust was also found to be related to seed source. The relative number of trees infected decreased as the longitude of the seed source increased. The preponderance of the data to date show that the source of seed should not be very distant from the planting site for best performance of the trees.

2. Hybridization

The resistance of hybrid white pines to blister rust is strongly related to the combined resistance of the parental species. Of these parent species used in a California study, western white pine is very susceptible, eastern white pine is susceptible, and Himalayan white pine is resistant. After 11 years exposure to the blister rust fungus, all hybrids between eastern and western white pines were dead; 92 percent of those between western white and Himalayan white pines were dead; but 66 percent of those between eastern white and Himalayan white survived.

Although the eastern white pine x western white pine hybrids have low resistance to blister rust, they have shown extremely high vigor in planting in northern Idaho. After 8 years the hybrids were about twice as tall as western white pine seedlings having the same female parent as the hybrids. Where blister rust is not a factor, the hybrid trees might greatly increase timber production.

The seed of hybrid trees and of selected superior trees will probably be produced in seed orchards. Contamination by foreign pollen can easily nullify the efforts of the tree breeder. In a study of pollen dispersal in Oregon, Douglas-fir pollen was trapped in large quantities in the center of a 3-mile-wide treeless area. Physical isolation in the Douglas-fir region does not seem feasible.

One other possibility of avoiding the contamination of Douglas-fir seed orchards by outside pollen is to establish the orchard at a different elevation than that of the parental trees. Thus the local pollen might shed earlier or later than the receptive period of female conelets in the orchard. An investigation showed this possibility unlikely. Pollen shedding time was observed to progress up-slope about 77 feet per day in the Cascade and Coast Ranges of Oregon and Washington. However, a seed orchard established at 600-foot elevation from parents at 2,600 feet had female conelets receptive only 8 to 10 days later on the average than local pollen--a favorable difference, but not enough to solve the contamination problem. It appears that some other approach to restricting contamination must be found.

Self-fertilization must also be considered in the production of superior hybrids or selected trees. In a study with white pine in Idaho, a general discrimination against self-fertilization was found. In most trees pollen from other trees was more effective in yielding germinable seed. But some trees were self-fertile and one such tree produced albino seedlings. Generally seedlings from self-fertilization have lower vigor than those from cross-fertilization. To insure that self-fertilization does not take place, self-fertile trees should be rogued from the seed orchard.

Hybridization sometimes is thwarted by apparent incompatibilities, often thought to be the result of failure of germination and development of the pollen. Basic research in California is aimed at uncovering reasons for lack of development of the pollen grain. One field of study is concerned with the metabolism of boron, known to be necessary for development of the pollen. Marked differences were found in the germination of pollen when exposed to different compounds and concentrations of boron. Another approach is concerned with the production of deoxyribonucleic acid in the pollen cells. This constituent of all cells is concerned with cell division. When a tagged precursor of deoxyribonucleic acid was introduced to germinating pine pollen, the radioactivity was found in the nucleus of the tube cell, which ordinarily does not divide. Further study of this abnormal process may reveal a cause of incompatibility.

Another cause for incompatibility in hybridization often is unequal chromosome numbers of the parents. Hybridization attempts between diploids and triploids probably would fail but those between diploids and tetraploid could produce triploids. To fill out the gaps in our knowledge concerning chromosome numbers, counts made for two eastern maple species showed that the trees were diploid, with $2n=26$. An oak previously reported to be tetraploid was found to be diploid.

Failures of fertilization are being studied also in Finland under a foreign research grant. The investigator in this project has found that failure of fertilization is common and results in incomplete development of the cone or the seed. In an attempt to identify trees which might be incompatible, he is examining various extracts of pollen and flowers with the serological technique, used so successfully to isolate antibodies in humans. Such a test might lead to easy identification of trees which could not be crossed.

Mexico is a valuable source of germ plasm for tree-breeders attempting to improve the pines. It has more species of pines than any other country in the world. However, identification is difficult and much effort in tree breeding might be wasted following improper selection. The Forest Service dendrologist has prepared a key which should aid in the correct identification of these relatively unknown Mexican species.

Because forest trees are undoubtedly heterozygous, the trees would not breed true. Vegetative propagation is the only way by which a selected tree can be reproduced without genetic change. In the pines the short shoots, or needle bundles, offer an opportunity for mass reproduction, but practically all past attempts to propagate pines from needled bundles have failed. To determine the conditions controlling the rooting and growth of these short shoots, grants have been made to scientists in Israel and in Chile under the PL 480 program. To date the investigators have determined that some hormonal control seems to be exercised by the terminal bud, and that growth of short shoots can be stimulated by one of the natural plant growth substances.

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D. TIMBER-RELATED CROPS

Problem

In addition to the five major products of the forest (timber, forage, water, wildlife, and recreation) there are a number of timber-related forest crops, some of which are sources of important industries in different parts of the country. These products include naval stores, maple sap, Christmas trees, and a group of minor crops composed of edible, medicinal, and decorative materials. Some of these crops when integrated with timber production greatly

enhance the total income of forest owners. These crops also provide a ready cash income which is not easily obtainable from periodic timber harvests. Many of the minor forest crops provide supplemental income to individuals in low-income areas and also provide opportunities for new industries. The research problem is to determine the potentialities of these timber-related forest crops and to develop the most efficient methods for their production.

Program

The present program of Forest Service research in timber-related crops includes a project in naval stores production and related tree improvement research at Olustee, Florida, a project in the production of maple products and related tree improvement research at Burlington, Vermont, and a small amount of research on Christmas tree production conducted as part of silvicultural projects in Michigan, North Carolina, and elsewhere.

Plans include initiation of a formal project on Christmas trees and other timber-related crops at Berea, Kentucky, and intensification of the part-time effort on these problems in various silvicultural projects in the eastern United States and the Northwest. The naval stores research will include fundamental studies of the physiology of oleoresin flow and applied research on the improvement of gum extraction techniques. The extraction phase of the research will be coordinated with equipment development research in the forest engineering project of the Forest Service at Auburn, Alabama. The research on maple sap production involves studies of physiology of sap flow, maple orchard management, and the development of strains with higher sugar content and sap yield, all in cooperation with the University of Vermont. Research on Christmas tree production includes the development of types of trees better adapted to Christmas tree use, as well as intensive cultural methods for diverse species, sites, and markets. Research on the miscellaneous timber-related crops such as nuts, greens, and drug plants will center on ways to increase the supplemental income to forest owners from this source.

Research on this project is closely coordinated with the naval stores and maple sugar processing of the Southern and Eastern Utilization Research and Development Divisions of the Agricultural Research Service. Some phases of the Christmas tree and maple sap production are studied by State agencies and universities often in cooperation with the Forest Service.

The annual Federal scientific effort devoted to this research by the Forest Service is 8 professional man-years.

Progress

1. Naval Stores

Estimates of heritability of oleoresin yield and other characteristics in slash pine have been obtained from studies of parent gum-yield selections, rooted cuttings, and control-pollinated and wind-pollinated progeny at Olustee, Florida. Heritability was found to be quite strong for gum yield (45 to 90 percent), moderately strong for bark thickness, diameter, and volume growth (5 to 67 percent), weak for total height at 10 to 15 years (5 to 16 percent), and weak to moderately strong for crown width (12 to 48 percent). The average heritability of perhaps 55 percent for gum yield indicates very good promise for genetic improvement in this trait.

A recent study in central Louisiana, which is outside the natural range of slash pine, has shown that the gum yield of slash pine plantations is not influenced by the geographic origin of the seed. Gum yields were compared in a 24-year-old slash pine plantation representing seven geographic seed sources from across the South. Differences in gum production among the seven sources were not significant. The results suggest that all slash pine plantations in Louisiana are equally suitable for naval stores operation, regardless of their seed origin. Since the yields were comparable to those from similar trees in Florida, the results also indicate that local soils and climate are not limiting factors in gum production.

The sulfuric acid solutions now used to stimulate oleoresin flow are corrosive to metal equipment and also require special safety precautions in handling. Forest Service scientists discovered that 2, 4-D and related compounds stimulated gum flow, but were lethal to longleaf pine though not slash pine. Exploratory studies on slash pine, now in their third year, show real promise on this species. The herbicide stimulant is resulting in as much gum flow as sulfuric acid. Furthermore, it opens new possibilities for development of disposable cups and gutters for gum collection, using materials that are not acid-resistant.

Intensive culture of slash pine plantations for oleoresin production and for the production of seed of superior strains will require a detailed knowledge of the response of slash pine to irrigation and fertilization. Basic information of this type was obtained from a greenhouse lysimeter study of the availability of N, P, and K from different sources to slash pine seedlings grown in Lakeland fine sand. Leachate analyses showed that virtually all NH_4NO_3 leached from the upper 12 inches of the profile within 4 weeks when water was applied at the rate of 4 inches per week. At the same watering rate, urea formaldehyde and potassium calcium pyrophosphate showed substantially lower leaching losses. No significant leaching of P was observed. The presence of pine seedlings in the lysimeters prevented or reduced leaching of N and K at low and intermediate

watering levels, but at the high level the seedlings were relatively ineffective in reducing nutrient losses. Chemical analyses of the seedlings showed greater nutrient uptake over a 17-week period from the readily soluble N and K sources at 1 and 2 inches of water per week. At the higher watering rate (4 inches per week) more N and K was taken up from the slowly soluble sources. These differences were reflected in seedling growth. Fertilized seedlings transpired from 30 to 80 percent more water than the controls, yet their water use per gram of dry matter produced was 25 to 50 percent less than that of control seedlings.

2. Maple Sugar Production

Genetic improvement of sugar maple to improve the sap yield and sugar content will require a considerable amount of basic information on the special flowering and fruiting characteristics of sugar maple. A study at Burlington, Vermont, showed that seed set of sugar maple following self-pollination varied between trees and was consistently less than under cross-pollination. Selfed progenies were extremely variable and exhibited some unusual characteristics such as albinism and colored cotyledons. The results provide guidance for further research on controlled pollination.

3. Christmas Tree Culture

Scotch pine, extensively grown for Christmas trees, varies widely in color, foliage density, needle length, angle of branching, and other characters that affect its sale value. Clonal propagation of selected trees by grafting is suggested as the quickest and most direct means for improving quality of the crop; the costs for such grafting are not definitely known, but it is believed to be economically feasible. The development of true-breeding improved strains that could be propagated by seed also is discussed in a publication by the Northeastern Station; this would involve selective breeding through several generations. A third approach could be through establishment of seed orchards; this, too, would require considerable time for progeny testing and removal of inferior trees or clones. Seedling seed orchards are recommended in preference to clonal ones. The discussion, although oriented to Scotch pine, applies in general to other Christmas tree species.

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II. WATERSHED, RECREATION, AND RANGE RESEARCH

A. FOREST SOIL AND WATER RESEARCH

Problem

All of the major rivers of the United States have headwaters in forests, associated rangelands or alpine regions. To derive the greatest benefits and protection from these headwater areas, improved knowledge of the management of watersheds and streams is needed. More than half the waterflow of the country originates in such areas. Whether this waterflow is beneficial or harmful, is well-regulated, sustained flow of good quality or erratic and silt-laden will be contingent to a major degree upon how the headwater lands are managed. Generally accepted estimates of water use indicate a doubling in demand by 1980. The most logical place to look for additional supplies or improved timing of such supplies of the quality needed is in the headwaters. At the same time there are constantly increasing pressures to use these same lands for a variety of products and services in addition to their watershed function. Additional research is needed to determine how best to adjust these several uses to give the necessary protection and development to soil and water resources.

Program

This work includes basic and applied research into the relationships of soil, climate, vegetation, and water and the development of methods and techniques to: (1) increase water yields or improve the timing of such yields under a variety of climatic, soil, geologic, vegetative and topographic conditions; (2) give adequate protection to soil and water resources while forest and related rangelands are being used for timber production, grazing of domestic livestock and big game, wildlife habitat, mining and forest recreation; (3) rehabilitate forest and related rangeland watersheds, that constitute sources of damaging flood runoff and sediment; and (4) aid forest soil development and improvement.

Ninety four and one-third (94 1/3) professional man years of effort were expended on this research during the past year.

Progress

1. Water Yield Improvement

This research is located in major terrain, climatic and vegetational complexes throughout the Nation. Its purpose is to determine management effects upon water yield from the Nation's forested and related range and alpine watersheds. This information is used to design management practices which will increase water amounts or change time of water delivery.

Water yield improvement research is being done in (a) the alpine snowpack zones of the West, (b) the vegetated snowpack zone of the East and West, and (c) in the vegetated rainfall areas of the Nation. Research results are discussed under these breakdowns.

a. Alpine snowpack zone. The alpine zone includes the area above timberline. The climate is cold and constant winds move the snow about continuously. Snow cover is seldom over two feet deep except for protected pockets in ravines or behind obstructions where the snow may drift 20 to 30 feet deep. The drifts melt slowly in the summer, maintaining streamflow long after lower elevation snow has melted. Chances appear good to influence timing of water delivery by piling snow in large drifts, thereby increasing late season runoff. Since evaporation losses from the snowpacks are negligible compared to evaporation losses from lower elevation reservoirs, delay in delivery of water until mid- and late summer is desirable.

In one study in the Colorado Rockies, snow fences were used to increase the depth of drifting and the amount of water available for summer streamflow. The fences were 8 feet tall and located upwind from the natural accumulation areas near main ridge lines. In mid-July an extra acre-foot of water was available for streamflow for each 62 linear feet of fence, and by mid-August there was an extra acre-foot of water for each 122 linear feet of fence. Other studies of snow fence spacing in Wyoming showed the most efficient spacing to be 325 feet between fences. At this spacing the snow fences trapped about 120 cubic feet of snow-water per linear foot of fence, as compared with 90 cubic feet per linear foot where 175- and 250-foot spacings were used. With the 325-foot spacing, the water equivalent of snow trapped was 0.4 acre-foot per acre.

Increased use of mountain slopes for winter sports has increased the danger to human lives and property, from avalanches. The structural avalanche preventive works so common in the Alps of Europe have been little used in the United States. To learn where and how such methods might be employed here, a Swiss specialist in avalanche control was brought to this country on a cooperative project with Colorado State University. His studies showed that of 71 avalanche areas studied in Colorado, about half could be controlled by structures and afforestation in the starting zone. On 6 tracks, diversion structures might be used. On 10 others, avalanche sheds would be more practical than control works. This information is valuable to railroads, highway departments and winter resort owners and also gives a basis for a future research program.

b. Forested snowpack zone. Below the alpine area lie the brush, grass and/or forested watersheds which supply most of the streamflow of the Western States and much of that in the North and northeastern sections of the country. In the West, forests in the snowpack zone hold the best opportunities of all forested areas for improving water yields through vegetation management. Precipitation annually averages 40-50 inches of water. About 45 percent of this appears as runoff. Preliminary studies of cutting patterns and other forest management practices which reduce interception and evaporation losses and increase the snowpack, indicate possible increases in water yield as much as 4 inches (20 percent). Little is known about the effect of various forest densities, cutting patterns, aspects, snow physics, etc. upon snow accumulation, ripening and melt.

A number of studies are showing that increases in water yield can be obtained by removal of forest cover. From one study the average annual increase in streamflow over 7 years from strip clear-cutting which removed 40 percent of snowpack timber in a 714-acre watershed in Colorado is 2.9 area-inches (170 acre-feet). The runoff peak is 2 weeks earlier after treatment. Nearly all the increased yield occurs during the spring freshet. Sediment yields are closely correlated with peak discharges. When the peak streamflow for the year is 12.5 c.s.m., the sediment

discharge is 400 cu. ft./sq. mi. This increases to 2300 cubic feet of sediment per square mile when the peak streamflow is 22.5 c.s.m.

To determine the effect of opening size and aspect on snow accumulation, snowpack depths were sampled in 5- and 10- and 20-acre clear-cut blocks and in uncut areas of lodgepole pine in Wyoming. With all aspects combined, snowpack in the clear-cut areas contained 2.5 inches more water than that of the uncut areas. Unlike previous studies conducted in California and Colorado, there is no significant block size relation apparent. Snow disappearance from the clear-cut blocks was 10-14 days earlier than in the uncut areas. The greatest response to clear-cutting was observed on east aspects where cut blocks accumulated 3.2 inches more water equivalent than the uncut.

To determine the magnitude of evaporation from snow in Colorado, flow of water vapor within and from the natural snow cover in a forest opening was estimated from vertical temperature profiles extending from within the soil through the snowpack and into the air. During winter observation periods, the average daily evaporation was 0.1 to 0.2 gms. per sq. cm. of snow surface, increasing to 0.3 gms. just before the spring melt. There was a free movement of vapor within the snow cover, with a substantial flow from the lower to upper layers of the snowpack.

A chemical evaporation suppressant, hexadecanol, reduced evaporation from snow surfaces by 32 to 70 percent when applied to the snow surface in the amount of about 12 pounds per acre. Hexadecanol did not significantly reduce summer soil moisture losses when applied to brush and red fir covered plots, even at rates of 35, 130, and 680 pounds per acre. This indicated it had no effect upon transpirational losses and supports other research that discounts such claims for the chemical. It did reduce evaporation as much as two inches of water per year from bulldozed, vegetation-free sites.

In the upper reaches of the Hudson River in the Adirondack Mountains, melting snow and spring rain during April and May account for 45 to 50 percent of the annual streamflow. This area is heavily forested, much of it with conifers that strongly influence snow accumulation and melt by intercepting snowfall and continually shading the ground surface. Measurements indicated that where 9 inches of water were accumulated in snowpacks under hardwood stands, only 6.9 inches of water were accumulated under conifer stands. Degree-day melt rates were 0.06 and 0.03 inch for hardwoods and conifers, respectively.

In ground-water studies in Michigan, a comparison between water available for ground-water recharge and actual recharge showed very close agreement. For the 1962 spring melt period, snowpack and precipitation measurements showed a total of 9.1 inches under a red maple-aspen stand and 6.6 inches under a jack pine stand, at the beginning of the snowmelt period. Hydrograph analysis of water table response showed a total recharge of 8.9 inches under the red maple-aspen and 6.4 inches under the pine.

Reforestation of abandoned agricultural lands and increases in density of the forests on cut-over and burned-over watersheds has significantly reduced streamflow of the 491-square mile Sacandaga River Watershed in New York State. Analysis of 50 years of streamflow record shows reductions have occurred in average runoff of 4.02 inches during the October to April dormant season, and 0.79 inch during the

May to September growing season. This indicates the main effect of increasing forest cover is the increase in water loss through greater snow interception during the dormant season.

Significant savings of soil moisture from logged subalpine forests are likely to continue for 16 years in the Sierra Nevada of California. In forests logged one year ago, 7 inches of water were saved as a result of the logging. In 5-year-old openings the saving had dropped to 2.9 inches, after 10 years to 1.2 inches, and after 12 years to 0.7 inch. Total saving of water in the 16-year period is estimated to be 34 inches.

In three years, sprouting from the root crowns of brush left after bulldozing a Sierra Nevada brush field totally obliterated the three inches savings in soil moisture measured in 1958.

c. Vegetated rainfall zone. The concept of water yield increase or change in timing of streamflow is based upon the fact that plants use water, some more than others. By encouraging the proper spacing of a desired species, one may increase or decrease the use of water by vegetation under certain conditions and thus increase or decrease water delivered to streams.

Two new instruments have been developed and tested to measure the rates and amounts of water lost by a plant. This information is needed to determine water consumption rates of different types of vegetation as a factor in planning watershed management. The first system consists of a plastic tent erected over a plant or plant community. Air of known moisture is blown into the tent and the increase in moisture content at the outlet times ventilation rates equals evapotranspiration of the enclosed plot. Transpiration has been successfully measured from a 24-foot tall pine with this system. The second system consists of a meter with which the velocity of sap flow in a living tree is measured. The sap flowmeter and transpiration tent were operated simultaneously on the same tree under a variety of conditions, and correlation between the methods was nearly perfect. These results strongly suggest that the sap velocity meter will be reliable for measuring transpiration of water from trees that are too large for the tent, and it is relatively simple to operate.

Removing 40 acres of canyon bottom vegetation from an 875-acre watershed in southern California resulted in increasing water yield by 25.2 acre-feet/year in 2 dry years. Investment and annual maintenance amortized at 4 percent makes the increased yield cost \$68 per acre-foot. Side slope conversion from brush to grass on 140 acres of the drainage is expected to produce an additional 18 acre-feet of water per year. This water will cost \$100 per acre-foot. These costs are roughly competitive to expected costs of imported Feather River water and could no doubt be significantly reduced on larger-scale operations.

For four conditions of plant cover growing in 10 or more feet of soil in the Great Basin area of Utah, the following moisture contents were measured at the time of maximum soil moisture depletion: bare soil - 34.37 inches of water; herbaceous vegetation only - 32.58; aspen stand only - 22.10; aspen stand with herbaceous understory - 15.48 inches of water. These data indicate the relative use of water by these different kinds of vegetation cover.

Little is known about the transport of water through roots of connected stems in clonal vegetation, and a better understanding of this phenomenon may be important when planning treatment of a species for improvement of water yield. The extensiveness of root connections in aspen and in Gambel oak was measured in the Great Basin area of Utah with radioactive tracers. Sodium arsenate was translocated to 26 oak trees from an injection into one stem, and 291 aspen stems received tracer material injected into 49 stems. Subsequent analyses of the soils in which these clones were growing indicated that the number of stems connected by functional roots is inversely proportional to the bulk density of the soil and directly proportional to the percent of soil aggregates greater than 2.0 millimeters in size. Thus cutting clonal streamside vegetation may not decrease water losses from the stream, if roots connect with plants far from the stream and these continue to transpire water.

Another study in Utah of evaporation and associated meteorological factors at 12 sites with diverse elevation, topography and vegetation reveals that although the range of evaporation from water-free surfaces is great, mean daily air and dew-point temperatures and wind movement can be used to predict evaporation losses. During the period June through September 1962, evaporation from Weather Bureau class A pans varied from 20.1 to 32.7 inches over the 12 sites. Evaporation rates above timberline on exposed ridges and in oak brush at 5,000 to 7,500 feet elevation were found to be higher than in aspen and aspen fir types at elevations from 7,000 to 8,500 feet. The highest evaporation rates occurred at sites with the highest mean air and water temperatures, wind velocities, and longest daylight periods. Wind appeared to be the dominant meteorological factor affecting evaporation.

Interception of precipitation by crown canopies of mature Douglas-fir forests in Oregon appreciably reduces rainfall that reaches the soil surface. Net precipitation is the sum of that falling through the canopy plus the water flowing down the stems of the trees. Throughfall for summer storms averaged 76 percent and stemflow was found to be negligible. Winter throughfall was highest for large storms, averaging 95.7 percent for 4 storms of 8 inches and over. In the winter dormant season, normal demands for water to satisfy evaporation, transpiration, and soil storage are minimal and water moves quickly through the soil mantle and into the streams. The water discharged from Douglas-fir forested watersheds during heavy winter storms probably very nearly equals the amount of rainfall received, suggesting that these forests exert somewhat less control over peak winter discharges than has been generally observed elsewhere.

The internal water balance of four species of hardwood trees was measured inside and outside of 50 by 50-foot plastic covered plots of deep soil in the southern Appalachian Mountains, using leaf-water deficit (WD) as the criterion. Soil and atmospheric moisture stress were related to variation in leaf-water deficit and dogwood was particularly responsive to both factors. These studies of the internal water balance of forest trees have suggested a regional Forest Drought Index (I) based on measurement of leaf water deficit or the water potential of leaves. Work with dogwood suggested (I) might be calculated $I = 2 (WD \text{ at } 6 \text{ a.m.}) + (WD \text{ at } 2 \text{ p.m.})$. The index, varying numerically from 0 to 70, would be widely useful in forest research, because many physiological processes, including transpiration, are primarily controlled by plant-water stress.

One aspect of water yield and timing that has received little attention is the influence of trees and litter relative to each other. Soil moisture measurements were taken from forest plots in Butler County, Missouri, some with trees removed and "litter-only" remaining. Some plots were "bare" of trees and litter; others had both "trees and litter"; while others had "trees" only. "Litter-only" plots were wettest. Profile drying was most rapid on the "trees-only" plots. The rate of drying at the 0-2 inch layer was about the same for the "bare", the "trees-only" and the "trees-and-litter" plots. Annual interception of precipitation by hardwood litter ranged from 2 to 4 inches in a North Carolina study. Dormant season litter interception accounted for about 60 percent of the total.

Suburbanization of formerly forested areas was found to reduce by half the relative infiltration of the Wissahickon Watershed near Philadelphia, Pennsylvania. This results in higher flood peaks and lower minimum flows in area streams. The data were obtained from ring infiltrometer measurements taken on lawns, fields, and associated woodlands.

Examination of the importance of dew in the hydrologic cycle in the forested mountains of West Virginia shows that while it is heaviest during the summer months, it can be ignored in most calculations for that area. Dew amounted to only 0.05 inch per month during the periods of heaviest formation.

Timber harvest effects upon water yield in West Virginia were shown to be in direct relation to the amount of timber removed. The four treatments ranged from a commercial clearcut to a light selection cut. Water yield increases from the clearcut amounted to 5 inches the first year following treatment, most of it in the growing season. In the 6-month period from May to October 1959, for example, increases were 3.0, 1.8, 1.4 and 0.3 area-inches for per-acre cuttings of 8.5, 4.2, 3.7, and 1.7 thousand feet board measure, respectively, but the increases on all areas are now almost totally diminished because of recovery of vegetation.

Wildfire removal of chaparral cover from watersheds in Arizona have increased water yield each year since the fire in 1959. Since this fire, annual spraying with 2,4,5-T has held the shrub canopy on one watershed to about 7 percent as compared to 30 percent on its adjacent unsprayed control. Following the third spray treatment, an increase in water yield of more than 4 area-inches was measured on the sprayed watershed, above that predicted. This is in an area receiving about 25 inches of precipitation per year. Sediment yields from the three watersheds averaged 20,000 tons per square mile the first year after the fire, but declined to 800 tons by the third year. There have been no sediment losses in the past year.

Plant succession on burned chaparral watersheds progresses from annual forbs and grasses through perennial herbs with final return to dominance of original shrubs. Seedlings of both desirable and worthless shrubs, rare in mature chaparral stands, are commonly observed following cover destruction.

2. Prevention of Watershed Damage

a. Forest management. There are many thousands of acres of forest and related lands that are still in good watershed condition. Increasing demand for use of these lands for timber harvesting, grazing, etc. requires that special attention be given to maintaining the present desirable condition of stable soils and controlled streamflow. This group of studies largely involves development of

land-use practices to give special attention to the prevention of watershed damage.

Sediment sources in California wildlands are being identified and evaluated by relating measured suspended sediment and reservoir deposition to meteorology, topography, vegetation, land use, and surface soil erodibility. These sources are predictable from rock type, vegetation type, and land elevation. Soils developed under brush cover have been found to have 30 percent higher erodibility than those developed under grass cover. Soils at low elevation are 40 percent more erodible than those found above 1,500 feet elevation. Soil studies in the Sierra Nevada of California show that soils developed from olivine basalt are less erodible than soils developed from quartzite and granodiorite. Soils on east aspects tended to be less erodible than those on north, south, and west aspects. Texture variability was significantly related to both elevation and slope in that particle sizes both larger than sand and of clay fractions decrease with elevation. These factors should be considered in developing land-use plans.

Studies on watersheds containing both farmland and forest in Wisconsin showed that the forested slopes in the unglaciated area help to control surface runoff from ridgetop farmlands. Of 35 storms that produced runoff from upland fields on three gaged watersheds, only three produced runoff at the bottom of the wooded slopes; and these three produced flows on only two of the three watersheds gaged.

A review of the state of knowledge about effects of burning in the Douglas-fir region of the Pacific Northwest reveals inconsistencies that need clarification by further research. It appears evident, for example, that burning generally increases amounts of available nutrients. There is, however, conflicting evidence concerning nitrogen and organic matter which ordinarily decreases, but may increase in grassland areas. Burning reduces the capacity of the soil to hold moisture, and in many cases, the rate at which water moves into and through the soil. The effect of burning is complicated by the severity of burn; for example, many of the detrimental effects of broadcast slash burning are limited to severely burned areas which average 3 to 8 percent of the total area logged. Erosion may be prevalent in severely burned areas, and removal of protective litter by a light burn may cause some runoff and erosion. Tree regeneration is not materially influenced by burning.

Fire, when used for seedbed preparation for pine in Arkansas, caused temporary deterioration of soil properties which are favorable to water absorption and erosion resistance, but four years following burning there was essentially complete recovery of all properties.

A recent study in the northern Allegheny plateau shows that snow accumulation under trees is in inverse relation to their crown densities. Half the seasonal snowmelt took place in hardwood stands before the spring warm spell began but melt was slower under the conifers. The more rapid melt rates under the dense conifer stands occurred later in the season. So perhaps a mixture of coniferous forest cover and open areas may provide the best land-use control of snowmelt runoff in that area.

On the upper Columbia River, deep snowpacks plus rain are often the source of floods. The influence of elevation, aspect, and cover on maximum snowpack water content in a western white pine forest were studied, indicating that elevation changes from 2,700 to 5,500 feet account for an increase of 30.1 inches in snowpack water. The effects of aspect vary with elevation, but there is a marked difference in the occurrence of melting between north and south slopes. Changes in the density of the forest canopy affect snow water content uniformly regardless of elevation, aspect or magnitude of snowfall. The largest increases in snow water content are produced by diameter and basal area reductions in the densest forest stands. The effects of any degree of timber removal from a western white pine stand of known total diameter or basal area can be estimated, in terms of snowpack water.

Control of overland flow and soil erosion depends, to a large degree, on adequate infiltration capacity of the soil. A basic study in Utah of the nature of the infiltration process was conducted on two of the several variables that affect infiltration rates (temperature and unsaturated conductivity). In a poorly aggregated loam, soil conductivity at various tensions increased with increasing temperature. On well-aggregated clay soils, conductivity increased with temperature, but only at low moisture tensions; at greater tensions, conductivity was inversely related to temperature. This is believed due to the inverse relation between soil moisture content and temperature at these tensions. At higher temperatures, the soil at a particular tension contains less water, and therefore, less conducting area than at lower temperatures. Results of this study are expected to lead to an improved understanding of the infiltration process and other related unsaturated flow phenomena.

b. Log road construction. In the Northern Rocky Mountain Region alone, timber harvesting in recent years has involved building approximately 1,600 miles of truck and jammer roads and 1,000 miles of tractor trails annually. Despite the numerous practices that have been employed to control soil erosion and sediment movement from these roads, a large proportion of the sediment reaching stream channels from forest lands still originates on roads.

A recent study, made on logging roads in Montana, northern Idaho, and eastern Washington, showed that road surface erosion and the distance sediment moves downslope from logging roads, are controlled mainly by watershed characteristics and road construction characteristics that can be changed.

The most important factor affecting distance of water movement before erosive cutting on road surfaces begins was found to be the proportion of soil particles and water-stable aggregates greater than 2 millimeters in diameter, on road surfaces. Thus, where soils have a low percentage of aggregates larger than 2 millimeters, the spacing of cross drains can be increased substantially by surfacing roads with fine gravel. Since differences in road gradient also have an effect on the distance to start of erosive cutting on road surfaces, roads should be designed having the most gentle grades possible. Distance to erosive cutting decreases with change of topographic position from upper to middle to lower slope position. This effect is believed to be due to large amounts of seepage flow coming from road cuts onto road surfaces as the road is situated further downslope. Shorter distances to erosive cutting were measured on south aspects. This is believed to be due to the combined effects of alternate freezing and thawing, which is more pronounced during early spring on bare and semi-bare roads on south aspects, and to larger runoff from higher snowmelt rates on south exposures. These results indicate

the need for closer spacing of cross drains on roads built across south-facing slopes and suggest, where a choice of aspects exists for locating a road, the north-facing aspect may be the better choice.

The distance that sediment moves from roads down slopes increases with increased spacing between obstructions and also with change in the dominant kind of obstructions in the order of mounds or depressions caused by trees and stumps, logs greater than 4 inches in diameter, rocks longer than 4 inches in cross-slope dimension at the ground surface, slash and brush, and major herbaceous vegetation. This indicates that, all other things equal, narrower protective widths between roads and streams are permissible where closely spaced windfalls, pushovers, and larger-sized residue from logging characterize the lower slope. The widest protective widths are required where sparse, and hence widely spaced, herbaceous cover is the dominant feature of the lower slope.

The quantitative relations revealed from these analyses have been transposed into a series of tables from which proper cross-drain spacings and protective widths can be obtained, if the watershed and road characteristics involved are known. Conversely, these relations can be employed to determine the extent to which it is necessary to alter a watershed or road design characteristic to meet given protective width requirements.

Sediment production after logging Sierra Nevada watersheds has been found to increase eightfold the first year after tree harvest and to diminish rapidly in succeeding years. Erosion on logging roads, skid trails, and landings across minor drainage channels was the chief source of sediment.

During a ponderosa pine cutting study from 1953 to 1960 on the Boise Basin Experimental Forest in Idaho, erosion and sedimentation on 16 small watersheds were held in check reasonably well because of careful advanced planning, close supervision of logging, and prompt application of intensive post-treatment measures. This is an area of moderate to steeply sloping terrain with relatively short slope distances from channel bottom to ridgetop. Sediment that reached the water courses originated primarily on haul roads. The closeness of a road parallel to a channel affected the frequency with which sediment flows reached a channel. Where undisturbed buffer strips of 30 feet wide or more were left between haul roads and stream channels, there was little sediment that reached the channel. Sediment moved down a channel at a faster rate with perennial streamflow than in channels with ephemeral flow.

On two National Forests of central Idaho, erosion measurements at 569 sites on 105 logging skidways revealed that (a) erosion is greater and rate of healing is slower on soil from granite than soil from basalt rock; (b) skid trails unavoidably located in ravine bottoms erode more soil than those on side hills; (c) control structures which tend to divert water off the trail onto undisturbed forest floors are superior to those which only slow down water and filter sediment within the trail; and (d) an increase in spacing between control structures is accompanied by increase in soil movement. Optimum spacing for control structures depends upon the percent of slope, location of the skid trail with respect to side hills or ravines, and the soil parent material. A table of recommended spacings of skid trails has been prepared under this study.

A series of abnormally heavy rainstorms occurring on an experimental area in Idaho provided an opportunity to study the effects of certain road-building practices on water movement, drainage, and road stability. A post-storm survey of a secondary haul road indicated that insloping a roadbed traversing a steep mountain slope and having 8 to 14-foot cut banks is more desirable than outsloping, as an erosion prevention measure. Specifically, the inslope should be designed to lead storm water away from the long fill on the incurve of the road as much as possible. Where culverts are to be used in major ravines, they should be located on the original water grade so that they do not discharge on the fill of the incurve but drain into the original channel. Where earthen cross-ditches are to be used, they should be located to discharge their flows on the outcurve of the road. Below the outcurve, the undisturbed side slope will tend to absorb road drainage and retard sediment flows before they reach a ravine or stream. Even with the best design of road drainage, erosion damage may be expected under abnormal conditions of rainfall.

3. Rehabilitation of Damaged Watersheds

This research is designed to develop techniques and management practices which will restore satisfactory surface flow and streamflow conditions and stabilize and improve soils on forest and range watersheds that have been damaged through past use and remain in unsatisfactory watershed condition.

a. Abandoned farm lands. In years past, many thousands of acres in the piedmont and upper coastal plain of the Southeast and South and other areas in the Lake States and the Central States were cleared from forest and put under clean cultivation. Serious erosion and deterioration of watershed conditions have resulted on many areas followed by abandonment. Difficult problems now prevail to stop the active erosion and to reestablish trees and other protective vegetation on those lands.

In southwestern Wisconsin, considerable success in tree planting was achieved by building a series of level bench terraces on slopes up to 32 percent with an adjustable, 6-foot wide, angle dozer. Costs averaged \$12.50 per mile. First-year survival from subsequent hand planting was 90 percent for 25,000 trees planted. Results of other planting trials in the same general locality ranged from 76.0 to 96.5 percent. Best results were on north aspects with the poorest occurring on a dry, hot, steep, southerly exposure where the planting was on a rocky, alkaline, prairie soil with bluestem grass cover. A table of species and age classes recommended for planting on various aspects and cover conditions has been prepared.

Pines are favored for erosion control in north Mississippi because they quickly cover the soil surface with abundant litter. The effectiveness of various pine species was evaluated by weighing the accumulated litter when the trees were four years old. Loblolly pines had grown faster and produced more litter than other species tested. Virginia pine excelled shortleaf and sand pine in both growth and litter production. Litter was closely correlated with height growth; loblolly strains which grew faster accumulated the most litter.

In an effort to determine the cause of mortality of seedlings planted for erosion control and watershed rehabilitation, loblolly seedlings were subjected to various stresses. In north Mississippi the ability of browsed seedlings to sprout and survive increased with seedling size and soil moisture. When tops of seedlings were clipped off to simulate damage from rabbits, 55 percent of the large Grade I seedlings recovered and survived the first growing season, as compared to 46 percent

of the smaller Grade III seedlings. Survival averaged 22 percent under artificial drought and 46 percent under optimum moisture. Large seedlings usually sprouted in the axils of primary needles, smaller ones in needle fascicles. Seedlings whose foliage was limited to sprouts were more vulnerable to tip moths than normal seedlings.

Unseasonably warm weather during the planting season often causes new terminal growth on loblolly pine planting stock, resulting in leaders that are easily broken in handling or susceptible to frost damage. A study comparing survival of dormant and nondormant planting stock revealed that frost in late March killed all the new terminals on actively growing stock, but those seedlings outplanted while still dormant remained green and thrifty. However, the frost injured seedlings quickly recovered and put on new growth. Survival of seedlings planted while dormant was 98 percent by midyear, and that of nondormant seedlings was 97 percent, indicating that the break of dormancy was not a serious factor in survival.

b. Overgrazed rangelands. Overgrazed rangelands constitute the chief flood and erosion sources for many western streams. Rangeland soils are often thin and sites are harsh. Rehabilitation costs may be high and past efforts have frequently failed. Research in development of newer and better procedures of rehabilitation is underway in several areas.

Soil studies in eastern Oregon and Washington show that over 40 percent of the variation in soil erosion hazard is accounted for by multiple variation of soil organic matter content, pH, total porosity and bulk density. This suggests that any land treatment designed to decrease erosion must be based upon increasing soil vegetative cover and the humus matter in the soil.

Applications of NPK fertilizers in 1957 in eastern Washington have given large increases in airdry vegetative matter, which still amount to more than two times as much, 6 years after treatment. Experience indicates that seldom does more than 30 percent of a watershed need treatment so that with costs of aerial application at \$1.50 to \$3.00 per acre and fertilizer at \$12 to \$15 per acre, the cost appears to be justified on a watershed basis.

Climate is one of the five factors contributing to formation of soil. Examination of sandstone soils formed from very similar parent materials on the east and west side of the Cascade Range in Washington showed a significant influence of climate on several soil properties. West slope Cascade soils had higher moisture equivalents, permanent wilting points, and total porosity than similar soils from eastern Washington and were less erodible.

Comparisons of seeded and unseeded slopes on the Wasatch Plateau of Utah show restoration measures have been effective in controlling overland-flow floods. Six years after treatment, soil bulk density was lower on all seeded areas—the greatest decreases occurring on sites that were initially most compacted. Where adequate plant cover existed prior to treatment, the disking and seeding reduced the density of live plant cover. Depleted sites, especially those on productive soils, responded favorably to artificial seeding. Results of this study led to the conclusion that in the application of artificial seeding measures to rehabilitate other similar areas, great care should be taken to include only those areas definitely deteriorated.

Twenty-three trees and shrubs, and 26 grass and forb species have been studied for their effect upon soil stabilization of Colorado rangelands. Blueberry elder has grown to 7 feet in two years from basal shoots and its leaf fall outweighed its nearest competitor by two and one-half times. White sweet clover produced the most foliage, of the grass and forbs, with 114 gms. per foot of row.

On an area of rangeland on the Rio Puerco drainage in New Mexico where about 90 percent of the rainfall runs off the surface, contour treatment with a Jayhawker ripper reduced the runoff by 96 percent in the first year. Even in the third year the reduction in surface runoff is 84 percent, which means much more soil moisture for plant growth.

c. Strip mined lands. Observation of early plantings on strip mined spoil banks indicates at least three years are needed for trees to establish a ground cover. Research is underway evaluating establishment techniques for a nurse crop to provide protection to the exposed soil during the interval before tree cover becomes established. A study designed to evaluate late summer and fall seeding dates shows that grasses and legumes sown at two-week intervals from July to October had an early ground cover ranging from 20 to 60 percent. After an unusually severe winter with repeated days of freezing and thawing, the fall seeded vegetation was reduced to a point where it did not provide an adequate cover on mined areas.

Fertility evaluation of spoil banks shows considerable variation in growth from the same spoil bank. It was also found necessary to mulch seeded plots to induce sprouting because of the severe crusting of the spoil. Where growth was poor or failed, an accumulation of salts was evident. Acidity values ranging from pH of 2.2 to 5.7 were measured in the study, making germination and establishment of seedling vegetation very difficult.

d. Burned watersheds. Nearly complete control of runoff and soil movement has been achieved within three years following the disastrous Deadwood burn in South Dakota. This control has been achieved by both native and seeded grasses both in areas contour trenched and those not so treated. Control was most striking during the third year when the area received up to 300 percent of normal precipitation.

Two years following the fire which destroyed the vegetation on the San Dimas Experimental Forest in southern California, flood peaks from two watersheds, 740 acres and 875 acres in size, were increased 800 times and 200 times during a 2.6-inch storm. Research on this area has shown that: (1) due to the great variations in climate, the chance of a successful broadcast seeding in any given year is uncertain; (2) rainfall intensities greater than one-half inch per hour are needed to produce appreciable flood peaks or debris loads; (3) contour trenching is not suited to the terrain, soil and climate of the area; (4) contour row planting of barley is the most effective erosion control measure. The problem of getting water into the soil of the area following fire is complicated by the presence of an ash layer and by the presence of a hydrophobic layer at or near the soil surface. A wetting agent was applied to the soil to reduce the surface tension of rain water and allow more rapid penetration of water through the hydrophobic layer. The results indicate a significant reduction in total debris movement and surface runoff from the treated plots.

4. Soil Improvement

a. Wetlands. To better understand and predict such bog watershed characteristics as rate and timing of runoff, and initiate effective bog site amelioration practices, more information is needed on how fast water moves through peat soils. Preliminary figures from a laboratory and field study of hydraulic conductivities of peat from Minnesota bogs show that these properties also vary for different peat materials but cover about the same range of conductivities as in mineral soils. Undecomposed moss peats had vertical hydraulic conductivities of approximately 1.5×10^{-5} cm./sec., or comparable to good aquifers of mineral soil. However, dense peats derived from other herbaceous materials were found to have hydraulic conductivities of about 7.5×10^{-6} cm./sec., or more comparable to poor mineral soil aquifers. The ease of draining these different peats would likewise vary considerably.

Some early research results from Minnesota have stressed the importance of expressing water contents of organic soils on a volumetric, rather than on oven-dry weight basis. This is because bulk densities (saturated volume basis) of sphagnum, sedge, and aggregated peats varied from 0.02 to 0.25 g./cc. as compared to mineral soils which normally range from 1.0 to 1.6 grams per cubic centimeter. It was also found that bulk densities of peat soils should be based on the volume when wet, rather than a dry volume, because of a volume reduction caused by drying.

Data from another Minnesota study have shown that water retention characteristics vary considerably with peat materials. With sphagnum moss peat in surface horizons, its total porosity was great and consisted of large pores, easily drained. On the other hand, aggregated and herbaceous peats from deeper horizons were more dense and had smaller pores. When these soils were drained under 1.5 pounds per square inch of tension, less than an inch of water was required to raise the water table 12 inches within the compacted herbaceous peat horizons, while 6 to 10 inches of water were needed to raise the water table an equal distance in the sphagnum moss peat. Therefore, the hydrologic role of a bog in a watershed will depend on the type of peat materials found within it.

5. Public Law 480 Projects

a. Monographic revision of the genus Tamarix. The Near East is the native home for many species of the genus Tamarix which includes one of the most troublesome phreatophyte species, saltcedar. To better understand the growth requirements of these plants as a possible avenue to their control, a research project in Israel under Public Law 480 is seeking to study and record the characteristics of each species and variety available. Collections of specimens have been made throughout Israel and in Turkey. Material from a number of herbaria throughout the world are being received and examined by the project staff, and a revised monograph of the genus will be published as soon as all data are assembled.

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B. FOREST RECREATION RESEARCH

Problem

Last year the National Forests received 113 million visits--a 7-fold increase since 1940. County, State, and National Parks, and private woodland areas have experienced comparable increases. Much of this use is concentrated on relatively small areas, and too often, new and old sites become depleted, worn and tired. Seldom has nature been able to hold the line. Administrators must know how to restore damaged sites, how to plan and select new sites, then be able to manage these areas so that a desirable recreation environment can be maintained.

To meet this obligation, we are learning more about the site and the management of its soils and vegetation, and we are learning more about the people who go to the forests, woodlands, and wilderness areas for their outdoor recreation enjoyment. Better information is needed as to the amount and kind of use these lands are getting now and are likely to receive in the future. Who are the visitors and where are they from? What are their interests and needs? How long and where will they stay? What are the impacts of recreation upon the economy and other forest resources in the area?

Program

Research at 8 of the 10 Forest Experiment Stations is underway toward answering some of these problems, and during past year considerable progress was made. Before discussing their research accomplishments, however, one major step should be mentioned--the establishment of cooperative recreation research units at three universities.

More men technically trained in forest recreation are needed in research and administration. To encourage more students to consider careers in outdoor recreation, and to assist in their training, the Forest Service has established cooperative recreation research units at Utah State University, University of Michigan, and New York State College of Forestry at Syracuse. At each university, one of our recreation research scientists is located at the School of Forestry. His job is to conduct recreation research, and to stimulate, help plan, and guide research in forest recreation by students majoring in the biological and social science fields.

Studies of the effects of recreation use upon the forest site are underway in the Northeast, Southeast, and the West Coast. Studies of the forest recreation user are underway in the East, Central and Lake States, Rocky and Intermountain regions, and on the West Coast.

A total of 21 man-years of scientific effort was devoted to forest recreation research during the past year.

Progress

1. Effects of Recreation on Forest Environment

An economic study of the impact of recreation development upon timber production was made on 3 National Forests in California--one within easy access for 8 million Californians; one moderately accessible; and one far removed from population centers. It was determined that the recreation capacity of the 3 forests could

be increased 1,000 percent through full development of all suitable recreation sites, yet the sustained yield timber production capacity following such development would be reduced only 13 percent.

Research to determine changes to the site resulting from campground use and restoration measures is underway in the Sierra Nevada. Forest understory vegetation which serves as a natural background for campsite privacy is critically important. A very simple, effective, and inexpensive line-of-sight device, nicknamed a "pantallometer," has been developed to measure the density and density changes of screening vegetation.

Lake depth is a critical factor in evaluating the recreation utility of lakes for recreation planning purposes. Inaccessibility of high mountain lakes in the western part of the United States makes field measurement of such lakes costly and time-consuming. Aerial photo interpretation techniques have been developed at the Intermountain Station to measure the depth of remote mountain lakes. Lake perimeters to depths of 15 feet can be measured at one-tenth the cost of field soundings. In a related study, aerial photo techniques have been developed to evaluate fish habitat quality and the general condition of high altitude trout streams. These advances will enable land managers to better estimate differences in recreational utility of various streams, required habitat improvements, and the effects of man-made differences such as roads and logging.

2. Forest Recreation Use

The Boundary Waters Canoe Area in northern Minnesota is the only "semi-wilderness area" in the National Forests. Recreation under primitive conditions is combined with logging, limited to protect scenic values. Two hundred and two interviews with a sample of visitors to all parts of the area, some parts of which were being logged, suggested good acceptance of the unique plan of management. Only 18 percent of the visitor groups reported noticing that logging was taking place, and only 5 percent of those who reported they noticed logging were bothered by it.

Recreation use in the Boundary Waters Canoe Area has been increasing about 12 percent a year since 1946—over 200,000 visits and almost 400,000 man-days in 1961. At this rate over one million visits would be tallied in 1976, but if this occurs, one might well ask, "What has happened to the solitude?" Many different types of visitors come to the area—canoeists, boat campers, fringe campground campers, cabin and resort guests, and one-day fishermen. No group is in the majority, but canoeists are the largest group. Unevenness of use is prominent in every one of these visitor types. A few places are jammed and large areas are unused or very lightly used. Over half of the visitors in each class were concentrated at 10 percent of the more than 60 peripheral lakes and streams. Maybe they don't really want solitude!

Canoeists were heavily concentrated at one of the 60 access points, but they spread out far beyond this point. Outfitters' advice and location of entry points to Canada's Quetico Park may be responsible for these concentrations. Improved visitor information and management to encourage more dispersed use might relieve these pressures. Boaters were numerous on all large lakes which could be reached directly by car or mechanized portages. Fairly substantial canoe use is tolerated by the canoeists and redistributing the over-concentrated use has possibilities for increasing capacity. Even low levels of boat use, however, eliminate the wilderness

for the canoeists. Boaters, on the other hand, tolerate heavy use. The boating-canoeing conflict seems to be the most pressing problem.

Twenty percent of the Nation's population live in the area extending from Iowa and Missouri through Ohio and Kentucky. Small, privately owned forest tracts, often in economically depressed rural areas, make up more than 90 percent of the forest land in these Central States; and they hold the key to forest recreation in the Midwest. Research has been started to assess the economic opportunities for developing private recreation enterprises. An inventory of existing enterprises (campgrounds, picnic areas, pay lakes, private beaches, hunting areas, riding stables, organized summer camps, etc.) was recently completed in cooperation with the Ohio Soil and Water Conservation Districts. Most of the facilities are located within 35 miles of large cities, such as Cleveland, Columbus, Cincinnati, and Toledo. Economically depressed rural areas in Ohio are more distant from population centers. An economic study to evaluate the problems and returns from existing privately owned enterprises and to evaluate the opportunities for additional enterprises has been started. Its emphasis is upon the depressed counties in southeastern Ohio.

A study to provide ways of measuring camping, picnicking, boating, and swimming at 13 developed sites was installed on 13 National Forests in the South. Estimates of recreation use were obtained by developing a ratio of man-hours of use to traffic counts by simultaneously measuring both. Relatively simple regression techniques relating axle counts to type of recreation use--camping, picnicking, swimming, boating, number of visitors, average party size, and peak use loads--produced inexpensive, reliable results. The method should be useful to all public agencies where estimates of use and visits on unattended recreation sites are needed.

A study of two widely separated forest recreation areas in the Northeast showed that visitors at the two areas differed significantly in distribution of age, occupation, income, education, distance from home, and length of stay. In addition, some relationships of visitor to activity were found to be important in one area but not in the other area. These differences were so great that visitor activities in one area could not be predicted from a survey of the other area. There were, however, some patterns of agreement in visitor-activity relationships in the two areas, and the study has recently been extended to several additional campgrounds.

A survey and planning guide for outdoor recreation was made in Washington County, Maine--an area with an abundance of forest, water, coastline, and other scenic and cultural attractions. Recreation developments are few and currently there is very little recreation use. This is further aggravated by the fact the county is economically depressed. The report suggests areas, sites, and facilities for development and for organizing to implement a recreation industry.

A study of the use of picnic facilities in Pennsylvania showed that picnickers seldom used tables more than 250 feet from a parking area. Even under extremely crowded conditions, tables beyond 400 feet were not used. People would spread a blanket between two occupied tables rather than walk the distance.

A user study of 4 campsites in New York State showed no differences in use by income class--income distribution was the same for all campsites. However, as one might possibly expect, camping parties in the high income groups traveled greater distances for their camping vacation experiences.

Studies in Oregon to determine which of 6 types of unmanned registration stations are best for obtaining information on wilderness use, showed that signs should be polite, firm, and direct. It further helped to explain why users were asked to register. A map of the local area was also found helpful in attracting response. Seventy-five percent of all user groups registered. An interesting and disturbing result of this study was that signs using the word "please" produced the poorest responses.

A study of campground use in the Cascades showed that 27 percent of the filled single-family campsite units were occupied by two or more family groups, even though there were empty family units available. Some variation in campground design appears desirable to satisfy the desires of these gregarious groups.

Rocky Mountain hunters apparently prefer undeveloped campgrounds. In 1961, only 9 percent of the hunters in 1,791 camps studied in Colorado and Wyoming used specially developed hunter camps; 24 percent used existing campgrounds or picnic sites; the remaining 67 percent used undeveloped hunter camps. Three-fourths of the campers used tents and stayed an average of 5 days. The traditional campfire, incidentally, seems to have less appeal to the hunter--58 percent of the hunters used a wood or gasoline stove for both cooking and warming.

In the high mountains of northeastern Utah, the idea is being explored of expanding the recreation opportunity by providing "pint-size" primitive units easily traversed on foot--A "micro-wilderness." The object of this investigation is to explore the possibility of making the entire perimeter of such an area readily accessible. Then, with an adequate system of trails and maps and signs, one may hike reasonably short distances to surroundings just as wild and lovely as those in the center of a large wilderness. If successful, the "micro-wilderness" concept could broaden the recreation opportunity and lessen the pressure on highly developed areas.

Three out of every ten publicly owned outdoor recreation areas and facilities in the United States charged user fees in 1959. ORRRC data were used for this study. Low fee returns are typical--34 percent of the charge areas recovered 1 to 19 cents per dollar of operation and maintenance costs through fee incomes. An additional 24 percent recovered 20 to 39 cents. Only 14 percent of the charge areas collected fees equal to or greater than their noncapital expenses.

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C. RANGE MANAGEMENT

Problem

Present forage production on vast areas of rangeland is far below the potential and falls short of meeting the demands for livestock and game grazing. Many areas, particularly in the western mountains, have been damaged to the point that watershed values are seriously impaired. Livestock grazing can also have serious impacts on production of timber and wildlife; consequently, there is urgent need for developing range management practices that will improve and efficiently utilize the resource.

Specific phases of the problem are: (1) to determine characteristics and requirements of range vegetation, (2) determine forage values, classify range condition and trend, and develop improved vegetation measurement techniques and range inventory procedures, (3) determine optimum management systems and intensities of grazing to obtain maximum production and efficient use of forage on the various types of rangeland, (4) determining effects of fire on vegetation and soils and developing practical guides for its use in controlling undesirable plants, increasing forage production, and improving quality, and (5) determining the identity and ecological relations of rodents and other range pests as a basis for their control.

Program

This is a continuing, long-term program of both basic and applied research at numerous locations in the various range plant communities of the West, Midwest, and South in cooperation with State colleges and universities, forestry and fish and game departments, and Agricultural Experiment Stations; as well as with the Smithsonian Institution, Bureau of Land Management, Bureau of Indian Affairs, Fish and Wildlife Service, Agricultural Research Service, numerous herbaria, private companies, and livestock associations or individual ranchers. In addition there are two PL-480 projects: germination of seeds of desert plants--Israel, and studies of botany, ecology, and biology of the principal species in mountain pastures of semiarid regions--Spain.

The Federal scientific effort involved in this research totals approximately 44 professional man-years.

Progress

1. Characteristics and Requirements of Range Plants

a. Ecology and physiology. Studies at Benmore, Utah, indicate that big sagebrush (Artemisia tridentata) may rapidly reinvade crested wheatgrass (Agropyron desertorum) range if seed producing sagebrush plants are not over 30 feet apart. A study of factors relating to brush invasion showed that proximity to a seed source was the most important factor in sagebrush invasion. The mean distance of maximum spread of sagebrush progeny was 42 feet from parent plants in a northeasterly direction, but upwards of 90 percent of

sagebrush progeny was within 30 feet of parent plants. Rabbitbrush (Chrysothamnus nauseosus) progeny spread much farther than sagebrush because of the plumed achenes. This was not considered a serious problem because it has been found that grass yields were not reduced by invading rabbitbrush as they were by sagebrush.

In Wyoming, seven major high-altitude vegetation types were identified and characterized according to use by livestock and game. The Carex-Deschampsia alpine turf type, occurring on the Snowy, Wind River, Absaroka, Beartooth Plateau, and Big Horn Mountain ranges, produced the largest amount of palatable forage for livestock and game. Similar vegetation occurred in open parks in the subalpine. Wet meadows in the subalpine usually were too wet to be grazed by sheep, but were used extensively by game. Drier open slopes and ridges of the subalpine zone were characterized by Festuca idahoensis, Poa sp., and Danthonia intermedia, all of low palatability to sheep. The Festuca-Primula-Caltha community in the Wind River Range produced little forage and appeared to be a pioneer stage of succession on soils derived from granite. The limited dwarf willow community on all ranges provided forage for livestock and game. Timber types of the subalpine zone were not considered as major forage types.

Near Globe, Arizona, reaction of understory vegetation to killing the chaparral overstory with herbicides was related to type of soil. Within 3 years after herbicide treatment of shrubs on quartzite soils, grass cover was three times as dense as that on untreated areas. Half-shrubs also increased on these soils following chaparral control. In contrast, grass cover on diabase soils, which are deep and sandy, was not affected by treatment. Cover of half-shrubs on cleared areas, however, was over three times as dense as that on check areas.

Studies on the Santa Rita Experimental Range in Arizona show that followup control of mesquite (Prosopis juliflora var. velutina), may be necessary for several years because of the persistence of viable seed. About 45 percent of mesquite seed in pods germinated during the first two growing seasons, compared with 16 percent of hulled seed. At the end of 2, 5, and 10 years the number of apparently sound seed amounted to 63, 47, and 10 percent, respectively, of the total number of seed buried. Viability of these seeds ranged from 86 to 89 percent.

Ten years' information on halogeton (Halogeton glomerata) in Utah shows that, within a given area, the presence of halogeton on crested wheatgrass range is influenced by three main factors: (1) weather, (2) soil salts, and (3) grazing. Halogeton has been most abundant in years of relatively high precipitation in spring and summer. On four spots where halogeton invaded, total soluble salts ranged from .08 to .65 percent in the 0-6-inch depth, .23 to .71 percent in the 6-12-inch depth, and .82 to 1.50 percent in the 12-18-inch depth. On adjacent areas (within 20 feet) where halogeton did not invade, comparative ranges of total soluble salts were only .04 to .08 percent for all 3 soil depths. Halogeton was most abundant on units that had been grazed heavily.

Studies in the Ozarks indicate that the persistence of little bluestem and Indiangrass under seasonlong heavy grazing may be due to the location of their growing points. Generally, the growing points of the vegetative culms of Indiangrass and little bluestem do not elevate enough to be removed by

cattle grazing; but the vegetative growing points on big bluestem could be removed. Consequently, the latter is more easily damaged by grazing than the other two species.

Laboratory tests in Idaho indicate that the highest temperature to which bitterbrush seeds are normally exposed in the field is not a limiting factor in natural reproduction of bitterbrush. Germination capacity of seeds exposed to dry heat at 175° F. for 5 hours was not significantly different from that of seeds exposed to room temperatures. However, five-hour exposure to 190° F. and 205° F. decreased germination 9 percent and 24 percent, respectively, while 220° F. was lethal to over 99 percent of the seeds.

In the Ozarks, radioactive tracers were used to study the absorption and translocation of herbicides in woody species. Absorption and translocation of C¹⁴ labeled 2,4,5-T was found to be highest in early spring, decreasing during May and June, and increasing again in July, August, and September. There was no correlation between soil moisture stress and translocation rates. Respiration rate in the leaves is highly variable during the growing season and generally parallels the rate of translocation.

b. Plant identification. A cooperative publication with the University of Montana, "Winter field key to the native shrubs of Montana," fills a long-standing need for a nontechnical guide on identification of native shrubs during the dormant, winter season. The key employs simple features of twigs, buds, bark, and leaves that are readily recognizable with a hand lens. Line drawings of distinctive features accompany brief descriptions of each of the 129 pertinent species. The descriptions include notes on taxonomic and ecological distribution and on food value for livestock and wildlife.

2. Range Vegetation Evaluation

a. Forage value. Studies in eastern Oregon suggest possibilities for developing new grazing systems that will maintain higher cattle weights in late summer and fall. Decline in weight of cattle grazing on mountain summer range has been found to correspond with decline in amount of protein available. Since recent data show that grasses in openings undergo a severe drop in protein 3 to 6 weeks before a like occurrence in grasses and sedges of forested areas, grazing systems to take advantage of these inherent differences of the different vegetation types on mountain grazing land are being planned.

A cooperative study with the University of Arizona indicates that cattle on semidesert range are very selective in their eating habits as they graze plants or plant parts that are much higher in protein than the principal grasses present on the area. On the Santa Rita Experimental Range, crude protein content of rumen samples from fistulated steers was about double that of handpicked samples of common perennial grasses. This explains the ability of cattle to perform satisfactorily on range forages that appear to be deficient in essential nutrients.

b. Vegetation measurement and sampling. In eastern Oregon, analysis of distance measurements on the most abundant species in each of 17 plant communities indicated that a plot 20 square inches in area would be the most appropriate size if the objectives were to obtain maximum information on a majority of species. This size plot provided more information than the 3/4-inch diameter loop.

In Arizona, multiple correlation based on records of herbage production, past stocking, and utilization provided good estimates of proper stocking for some semidesert cattle ranges. Multiple correlation coefficients exceeding 0.9 were obtained for several range units on the Santa Rita Experimental Range. Correlations were highest for units with good grass cover, consistent management, and relatively little browse.

Estimation of herbage yield is a highly desirable but time-consuming part of range research. A study in the California annual type showed that plant height, cover, and density are correlated with yield, especially when height multiplied by cover is included in the multiple correlation. These indirect estimators may be useful indicators of relative yield among range strata if absolute yield is not needed in this range type.

c. Range condition and trend. A survey in Nevada following a 3-year drought showed a 100-percent mortality for Indian ricegrass (Oryzopsis hymenoides) and considerable damage to budsage (Artemisia spinescens), littleleaf horsebrush (Tetradymia alabrata), and other shrubs. Following the moist winter of 1961-62, many of the shrubs made substantial recovery, and numerous seedlings of ricegrass emerged on sites where plants had died during drought. Undoubtedly, differences in resistance to drought are very important in determining composition of desert shrub communities.

On the Harvey Valley allotment in California, evaluation of the first 10 years of rest-rotation management has started. Preliminary data from one range unit indicate that the amount of soil surface covered by forage plants has decreased, but this may be due to the drought of the past four years.

Forty years' study of range trends in southern New Mexico show that droughts can be expected at rather frequent intervals. Black grama was reduced during extended dry periods to about the same minimum, irrespective of the degree of grazing; however, greatest recovery was on quadrats where less than 40 percent of the herbage was grazed. For best use and maintenance, tobosa range should be grazed during the growing season and black grama areas should be reserved for fall-winter-spring use when the grasses are dormant. Black grama reproduces largely by stolons that originate during the growing season. Tobosa is less sensitive to grazing and to fluctuations in precipitation than black grama because it is deeper rooted and confined largely to flood plains. Shrubs increased during the period of study, materially reducing the grazing capacity of the grasslands. Mesquite was the primary invader of the black grama type, whereas creosotebush and tarbush invaded the tobosa grasslands. Under the conditions observed, continual invasion of grasslands by shrubs is inevitable unless control measures are used. The results of the study are considered applicable to some 60 million acres. The major finding on livestock management was that a flexible herd be maintained wherein the number of breeding cows and bulls would be held at about 60 percent of the lighter herd. This permits stocking reduction as much as

40 percent through selling all yearlings and replacement animals in years of poor forage growth.

3. Livestock Grazing Practices

a. Native ranges. On cheatgrass range in Idaho, daily gains of weaned calves averaged 1.5 pounds per head during a 7-month grazing season from April until late October. Daily gains of about 2 pounds per head were obtained during the green feed period of April to June, but dropped to about 1 pound per head during the fall season. Summer-growing annual weeds such as Russian thistle provided some supplemental green feed during the summer and fall when cheatgrass herbage was mature and dry. Fluctuation in quantity and quality of forage associated with weather is reflected in variable seasonal gains and a threefold difference in grazing capacity in the 2 years. Under moderate and heavy use animal days of grazing per acre were 5 and 7 days, respectively, in 1961 compared to 13 and 23 days, respectively in 1962. Practical methods of meeting such fluctuations and increasing the productivity of these ranges are objectives of continuing research.

By the eighth year of study on the Starkey Experimental Forest and Range in Oregon, dramatic differences were found in weights of livestock for different grazing intensities. Under a moderate rate of stocking (7-1/2 acres per AUM) 77 cows gained a total of 3,311 pounds in 3-1/2 months on mountain summer grazing land. Under a light rate of stocking (10 acres per AUM) 58 cows gained a total of 3,190 pounds. Under a heavy rate of stocking (5 acres per AUM) 94 cows lost a total of 2,538 pounds. Such findings point to the good business of grazing range lands under moderate stocking rates to achieve better gains. Two successive summers of below average precipitation have contributed to this striking disadvantage of heavy stocking rates. However, a long-term projection of the available data over a variety of summer growing conditions indicates the superiority of moderate stocking.

In Colorado, 17 years of grazing pine-bunchgrass range with cattle showed that 30-40 percent use of the dominant grasses and sedges was optimum for sustained forage and livestock production. At that intensity plant vigor of Festuca arizonica and Muhlenbergia montana was not lowered, in contrast to an appreciable decrease in vigor when utilized over 50 percent. Perennial grasses and sedges produced 335, 446, and 148 pounds of air-dry herbage after 17 years' grazing at 10-20 percent, 30-40 percent, and over 50 percent levels, respectively. Depth of penetration and volume of root systems of desirable grasses were reduced on heavily grazed ranges. Average gains of yearling heifers June through October were 210, 201, and 151 pounds under light, moderate, and heavy grazing rates. Based on weight gains, market values, and operating costs, net returns per section for every \$100 from the 30-40 percent use were \$73 for the lightest grazing and \$55 for the heaviest.

A study on Idaho fescue grasslands in the Big Horn Mountains of Wyoming is showing the possibilities of obtaining greater weight gains on steers from rotation grazing than from seasonlong grazing. Over a 3-year period, rotation grazing has produced an average of 2.1 pounds per day on steers, compared to 1.9 pounds per day on steers grazed seasonlong at the same stocking rates. Per-acre gains averaged 52 pounds from the rotation grazing compared with 50 from seasonlong grazing. Where stocking was 50 percent

greater and the pastures grazed in rotation, per-acre production was increased to an average of 63 pounds per acre but the individual steers gained less, averaging only 1.7 pounds per day.

Studies on semidesert range in Arizona show that resting the range in alternate summers increased grass production, particularly where mesquite is controlled. On ranges stocked to graze 40 percent of the perennial grass herbage each year, deferring grazing during the growing season in alternate years since 1957 resulted in 34 pounds more perennial grass herbage per acre per inch of summer rainfall in 1962 than in 1954 under yearlong grazing. Under this management grass yields increased 76 percent in 4 years.

In Louisiana, practical combination of supplemental feeding, herd management, and controlled grazing produced more than \$70 worth of calf per cow annually. This is about triple the production of the average range cow in the area. This demonstrates that raising beef cattle on forest range in the Deep South can be profitable for the well-managed property.

b. Improved ranges. On the Front Range of Colorado, Sherman big bluegrass is proving to be an outstanding producer of forage and beef. During the past 4 years, this grass produced an average of 97 pound weight gains per acre on yearling heifers. Next best was a mixture of crested wheatgrass, smooth brome, and yellow sweet clover on which an average of 72 pounds of beef per acre was produced during the same period. Crested wheatgrass, intermediate wheatgrass, Russian wildrye, and smooth brome seeded in pure stands were all less productive. All these exotic species have outproduced the natural vegetation.

At Benmore, Utah, a cooperative study with Utah State University indicates that in dry years a protein supplement can improve weight of cattle grazing mature crested wheatgrass. As result of grass regrowth in 1961, animals gained weight throughout the summer and fall periods and the effect of a protein supplement was unnoticeable. However, in 1962, with the absence of summer and fall rains, a protein supplement, consisting of 3/4 pound soybean meal per head per day, had noticeable effect on lactating cows in all periods from June through December. The beneficial effect of feeding protein supplement to cows began to show on calf weights in late summer and was most pronounced in early fall.

In southern Georgia, studies are underway to determine the feasibility of harmonizing cattle and timber production on intensively managed pasture units. Experimental grazing was initiated in the spring of 1961 when trees, planted as seedlings in 1957, averaged about 12 feet high, and seeded grass stands were one year old. Trees were pruned to a height of 8 feet in late winter 1962 when they averaged about 16 feet high. Average annual beef gains of 142, 182, 208, and 244 pounds per acre were obtained from pastures planted to carpetgrass, Coastal bermuda, dallisgrass, and Pensacola bahia, respectively. Liveweight gains per acre of 233, 192, and 157 pounds, respectively, were obtained on pastures with no trees, with trees spaced 20' x 20', and trees spaced 12' x 12'. These results, though preliminary, afford important management clues in supplying feed for cattle grazing plantation areas in the flatwoods country of the Southeast.

Beef cattle production on annual-plant ranges in California was increased 60 percent by fertilizing the range with sulfur, and 150 percent by using sulfur plus nitrogen. Based on the costs of fertilizing and the sale price of the cattle, net returns from spring grazing were more than \$28.00 and \$36.00 per acre, respectively, from sulfur and sulfur-plus-nitrogen fertilization. The costs of the fertilizer programs were paid for the first year and a profit returned.

In northern New Mexico, research has shown that past reluctance to use range seeded to crested wheatgrass for lambing is unfounded. Weight gains of lambs from ewes grazing crested wheatgrass were as much or more than those from ewes grazing native sagebrush and juniper range. Also, larger lamb crops were obtained on crested wheatgrass range. Use of crested wheatgrass required fewer acres and therefore was much more efficient use of the land.

4. Burning for Range Improvement

A study on effects of burning on important bunchgrasses of southern Idaho revealed damage to Poa secunda 2 years after burning that was not obvious one year earlier. Large Poa secunda plants burned at 200° F. and 400° F. in July and 200° F. in August had significantly smaller basal areas than unburned plants. Apparently, the impact of heavy grazing (which occurred the first year after burning), coupled with only slight damage from burning the first year, produced a combined detrimental effect. In contrast to Poa secunda, the second-year observations on Sitanion hystrix indicated essential recovery of plants that showed damage the first year following fire. Stipa thurberiana and Stipa comata, the most seriously damaged species, continued to show extensive damage 2 years after burning.

In Florida, fire is used to improve quality and quantity of range forage. Yields of total herbage increased from 66 pounds per acre 3 weeks following a winter burn to 3600 pounds per acre in the fall of the second year. Pineland three-awn grass comprised 97 percent of total herbage 3 weeks after burning, 90 percent after 5 weeks, and 73 to 83 percent thereafter. In terms of meeting requirements for proper cattle nutrition, crude protein in this forage varied from very good (13 percent) at 3 weeks to inadequate (4 percent) at 5 months, while phosphorus and calcium were never adequate. Sprouts following the fire contained only 0.14 percent phosphorus and 0.10 percent calcium. Phosphorus content declined over the 2-year period; calcium remained fairly stable. Supplemental minerals are fed to offset phosphorus and calcium deficiencies. These studies are continuing.

In central Louisiana, moderate to heavy grazing or periodic burning increased grass production on slender bluestem ranges. During 8 years' study of grazing intensity and burning, yields declined on ungrazed range and increased on grazed units. Burning prior to the beginning of growth in 1955 materially increased the subsequent grass yield on ungrazed range but not on grazed units. It was concluded that moderate grazing (removing about 45 to 50 percent of the grass growth) with prescribed burning on a 3- to 4-year cycle will maintain high range grass yields with a minimum of damage to longleaf pine seedlings.

In Arizona, burning of grasslands to control invading juniper showed that fires in January and March killed 70 to 100 percent of one-seed juniper trees under 3 feet tall but only 30 to 40 percent of the larger trees. Black grama and galleta, the dominant forage grasses, were damaged only slightly; they regained their initial production within 2 years after the fires.

5. Range Pest Influences and Control

In Idaho, study to date reveals that approximately one-third of the annual bitterbrush seed crop may be destroyed by insects. Study of pentatomid bugs (Chlorachroa sayi Stal) in 1962 showed that this insect is responsible for seed blackening. In mid-July, shortly after natural seed drop, 84.3 percent of the seed from cages having pentatomid bugs were completely blackened, compared to only 1.5 percent where the bugs were absent. The appearance of spotted seed in cages without bugs casts suspicion on a sucking insect as the causative agent of spotting. Psyllid nymphs (Psylla sp.) were abundant in the spaces between seed husks and calyx tubes during the seed development period. Study is continuing to determine whether this sucking insect injures bitterbrush seed.

In western Colorado, seventy-four percent of the material eaten by pocket gophers was above-ground stems and leaves and 26 percent was roots. These records, based on stomach analyses of 397 animals captured over a 2-year period, indicate that pocket gophers, which normally remain underground, take mainly stems and leaves of forbs during the June-September period. Pocket gophers formerly were believed to be underground feeders, but this new information suggests the possibility of surface baiting in control operations. The influence of gopher feeding habits and burrowing activity on the range vegetation and on the productivity of range soils is still under investigation.

On Black Mesa, Colorado, in 1962, seedlings of Parry's rabbitbrush were only one-tenth as abundant on Thurber fescue grasslands from which pocket gophers had been excluded for 5 years as on comparable areas from which gophers had not been excluded. Rabbitbrush seedlings averaged 384 per acre within eight 1-acre gopher exclosures compared with 3,790 per acre within eight similar gopher-present areas nearby. At the beginning of the study in 1957 gopher population averaged about 20 per acre.

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D. WILDLIFE HABITAT MANAGEMENT

Problem

Wildlife habitat supplies food, cover, and water and is the key to optimum game production. Management of the habitat is complex. Each kind of animal has rather specific habitat requirements, and these must be balanced against requirements for production of water, timber, and forage for livestock. Demands for all uses of forest and related rangelands are increasing, and serious conflicts have developed; consequently, wildlife habitat research is needed to develop the most effective and harmonious management practices for the various vegetation types and associated wildlife.

Specific phases of the problem are: (1) to devise methods for revegetating depleted habitats or improving those naturally unproductive and (2) to develop and evaluate management systems that allow most efficient use of the resource through studies on the nature and degree of competition between wildlife and livestock, effects of timber production and cutting practices on forage for wildlife and livestock, and reciprocal effects of forage production and grazing on timber.

Program

This is a continuing, long-term program of both applied and basic research at numerous locations in the various plant-animal communities throughout the United States. It involves interrelations of wildlife and livestock and integration of timber and forage values to allow optimum production and utilization of each. Studies are conducted in cooperation with various State and Federal agencies such as fish and game or forestry departments, Agricultural Experiment Stations, Fish and Wildlife Service, Soil Conservation Service, Agricultural Research Service, Bureau of Land Management, and in some instances with livestock or sportsmen associations, private companies or individuals.

The Federal scientific effort involved in this research totals approximately 23 man-years.

Progress

1. Wildlife Habitat Improvement

In southern Idaho, evaluation of plant species for revegetating deteriorated deer winter range has revealed that only a few species survive the seedling year and exhibit a good growth rate thereafter. In several trials during the past 6 years, bitterbrush (Purshia tridentata), desert bitterbrush (Purshia glandulosa), and cliffrose (Cowania stansburiana), survived and grew well on soils derived from granitic parent material. These three species also exhibited excellent first-year growth and survival last year on acid volcanic parent materials. Wedgeleaf ceanothus (Ceanothus cuneatus) responded well in seedings on soils from granitic parent materials, but it suffered top dieback during the 1961-1962 winter. Curleaf cercocarpus (Cercocarpus ledifolius) seedlings failed to survive the summer on granitic soil of the south fork of the Salmon River winter range. This failure, along with previous failures on winter ranges along the Boise and Payette Rivers, indicates that curleaf cercocarpus is difficult to establish in areas to which it is not native.

Research in California shows that one acre well-stocked with seeded bitterbrush plants will provide feed for a 100-pound deer for as much as ten months. Browse seeding is no substitute for other deer management programs, but it does provide another tool for game and land managers to use where needed. It is particularly useful following wildfire on deer range. On many burned or severely deteriorated ranges, important browse has little or no chance of coming back naturally and seeding will materially hasten range recovery.

In the Black Hills of South Dakota, antelope bitterbrush has shown good promise for planting on depleted deer winter range. Though not native to the Black Hills, it has been more easily established from seed and grown more rapidly than the native chokecherry, pin cherry, true mountain mahogany, serviceberry, silverberry, and common juniper.

In Virginia, wild turkey populations of the Broad Run area, Jefferson National Forest, have responded spectacularly in a pilot test of habitat improvement utilizing several large management compartments. Beginning with 12 birds in the fall of 1957, the population had increased to more than 100 birds by 1960. Area management included provision of supplemental forage clearings planted to bluegrass and ladino clover, small impoundments for watering, and stepped-up timber cutting and stand improvement measures. Although there have been general increases in turkey numbers elsewhere, this local and substantial rise undoubtedly reflects favorable response to land management activity in the test area. Very heavy use of forage clearings by broods for insects and weed seeds plus year-round clipping of greens probably have been major contributing factors.

At Nacogdoches, Texas, greenhouse studies are under way to determine whether some of the most important browse plants can be propagated by rooting. Results to date show that the rooting percentages of the five most promising species were: American beautyberry, (Callicarpa americana) 66; flowering dogwood, (Cornus Florida) 76; yaupon, (Ilex vomitoria) 10; black willow (Salix nigra) 49; and common greenbrier, (Smilax rotundifolia) 65.

2. Integration of Wildlife, Livestock, and Timber Production

Studies and observations in Utah show that adequate yearlong forage is essential for maximum deer herd productivity. Overgrazed foothill range will carry large numbers of deer through the winter, but sufficient herbaceous forage is often lacking during the early spring period. Intermediate elevation overgrazed range may provide adequate browse for deer in the fall, but may be deficient in new forb growth for females in late pregnancy and during fawning season. Depleted summer ranges may provide survival rations for overpopulations of deer, but do not provide nutrients sufficient for high herd productivity.

Near Nacogdoches, Texas, studies were made of timber stand structure and the abundance of deer forage in southern shortleaf-loblolly pine-hardwood forests. Clear-cut, moderate overstory, and uncut stands, respectively, yielded 1600, 790, and 426 pounds of browse, forbs and grass (air dry) per acre. Midstory exerted a stronger influence than dominant overstory, i.e., a dense midstory permitted only a light forage yield. Production was somewhat further reduced when midstory was overtopped by dominant trees. Browse plants palatable to deer are generally more tolerant of shade than are undesirable species. It was concluded that usable amounts of forage suitable for deer can be produced in pine-hardwood forests that are well stocked, but not encumbered with a dense hardwood midstory.

In Georgia and Florida, slash-longleaf flatwoods generally appear the most productive for turkeys, less productive for quail, and least productive for deer. Wiregrass and saw-palmetto types are about equally productive for quail with the gallberry type rated low in this respect. Both the saw-palmetto and gallberry types have a high potential for turkeys largely because of abundant seed and fruit production. All types appear somewhat marginal for deer, with a slightly higher potential in the wiregrass and saw-palmetto communities.

Studies in eastern Washington and Oregon have shown that thinning dense stands of regenerating ponderosa pine results in big increases in understory vegetation for game. At the end of the third growing season following tree removal, the thinned plots were producing 3 or 4 times as much herbage as the unthinned. Grasses and forbs each accounted for about half the total increase with shrubs contributing less than 10 percent. In future years, shrubs will provide a much larger proportion of the total yield. Forbs showed a greater capacity to produce dry matter than grasses when pine canopy exceeded 45 percent; when below 45 percent grasses were superior producers.

Studies of deer summer ranges in Utah show that invasion of disclimax aspen communities by conifers over widespread areas is reducing the amount of aspen, volume of forage, and intensity of deer use. Forage in aspen, with only small conifers present, was eight times greater, and deer use about seven times greater than in aspen stands on similar sites that are now dominated by conifers. Since many of these areas are too poor to produce merchantable timber, the natural succession from aspen to conifers should be altered or reversed.

In the Lake States, managed second growth hardwoods with an overstory of 75 square feet of basal area per acre are producing 10 times as much deer food as are uncut stands. This is due both to the increased production per stem (about 4 times as great) and to the greater number of browseable stems (almost 2-1/2 times as many) in the thinned stands. At best, however, the annual production is still very low, amounting to only 21 pounds per acre. The most important browse species were sugar maple and white ash. At the same time, a considerable portion of the yield was furnished by such pioneer species as red elderberry, hazel, and black cherry, suggesting that consideration of road edges, and similar sites is essential to properly evaluate browse production.

During the first year after improvement selection cutting on the North Kaibab Plateau, Arizona, production of perennial grasses and sedges was reduced slightly. Thereafter, production of understory vegetation increased to a peak of about 200 pounds per acre the sixth year after logging, then began to decline. However, 11 to 15 years after logging, production was still higher on cutover areas. Deer use, as measured by accumulated pellet groups, was several times that of unlogged areas between 3 and 11 years after logging.

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III. FOREST PROTECTION RESEARCH

A. FOREST FIRE

Problem

Wildfires are a constant threat to our forests and wildlands and a repeated drain on both natural resources and public funds. In 1960, the estimated total direct cost of wildfire control in the United States was about \$100 million. Currently, it is estimated to be about \$140 million, up about 40 percent. Nationwide, forest fires number over 100,000 a year and burn over about 6 million acres of land. Both number and burned area vary somewhat from year to year with length and severity of the fire season, but recent years have shown no meaningful downward trend.

For a number of years fewer than 5 percent of the total fires that start have been causing 90 percent of the cost and damage from fire. These are the run away fires. After they become large, high costs and damage are inevitable. But most could be controlled at small size if the potential for run away behavior could be identified in advance. The kind of knowledge that will enable fire control specialists to make such identifications is accumulating, but much remains to be learned. Meanwhile the development of fire suppression techniques has to proceed on the basis of limited knowledge. These interim fire fighting methods are satisfactory for controlling the average fire. They are not adequate for controlling the most aggressive. The more exacting techniques such fires require, depend on ability to calculate and predict the behavior of large fires. This can only be achieved through continued intensive research.

Only slightly less urgent is the need to develop safe and effective techniques for using fire purposefully on wildlands as a direct protection measure and for other land management purposes. In recent years, "brush" fires on unmanaged wildlands have accounted for much of the fire bill. As populations increase these lands are becoming more and more important in our national economy---as watersheds, recreation sites, ranges for wildlife, and even residential areas. Prescribed fire offers much potential as a tool for land management plus a means for more effective protection at less cost on these lands.

Program

The Forest Service has a continuing long-term program involving numerous disciplines in the physical, biological and social sciences engaged in both basic studies and application of known principles to the solution of wildland fire problems. The research is conducted at the Macon, Georgia; Missoula, Montana; and Riverside, California Forest Fire Laboratories as well as at projects in Fairbanks, Alaska; Portland, Oregon; Berkeley, California; Fort Collins, Colorado; Flagstaff, Arizona; Salem, Missouri; St. Paul, Minnesota; Upper Darby, Pennsylvania; Asheville, North Carolina; and Alexandria, Louisiana.

Weather and fire behavior research at the three fire laboratories and at Portland, Salem, Berkeley, and Alexandria is cooperative with the Department of Defense, Weather Bureau, National Science Foundation, National Bureau of Standards, State conservation agencies, universities and other research institutes. Fire prevention studies relating to man-caused fires at Riverside, Berkeley, and Alexandria are cooperative with the University of Southern California and the Universities of

Louisiana and Mississippi, respectively. Lightning prevention research at Missoula is cooperative with National Science Foundation, Weather Bureau, Montana State University and University of Washington. Fire control systems and methods research at all locations is cooperative with State and local conservation agencies, universities, field offices of other Federal agencies, private landowners, and private industry. Use of fire studies are cooperative with State and local conservation agencies, Weather Bureau, universities, and public and private land managers.

One fire behavior study is conducted by Instituto Nacional de Tecnica Aeronautica Esteban Terradas, Madrid, Spain under PL-480 contract.

The current Federal scientific effort devoted to this research is 51 professional man-years. This includes 18 to weather and fire behavior; 11 to fire prevention; 16 to fire control systems and methods; and 6 to fire use.

The Forest Service is the only Federal agency which conducts forest fire research. In addition, the Forest Service, at the Forest Products Laboratory, and several other federal agencies conduct or sponsor research on fire problems relating to missions other than forestry. All this group, in common with the Forest Service, have interest in basic laws and principles of combustion and extinguishment. Work is coordinated closely through several mechanisms. The Committee on Fire Research of the NAS-NRC assumes national leadership in this process. Some States and universities conduct short-term forest fire studies, though mostly through cooperative agreements with the Forest Service.

No major lines of work were terminated during the year.

Progress

1. Weather and Fire Behavior

a. Fire physics. Understanding the fundamental processes of ignition, combustion, and fire behavior is essential, and is being acquired, for development of specific techniques for suppressing wildfires and using controlled fires.

Fire whirl, a severe wildfire behavior phenomenon involving high energy output and rapid engulfment of additional area, is being duplicated in miniature and measured in the Southern Forest Fire Laboratory. The burning rate of fuel triples when the vortex forms. Almost all of the energy comes from burning fuel. Updraft velocities in the central vortex measure 1.4 times the horizontal velocities, and many times as great as the updraft velocities in ordinary type convection columns over heat sources of comparable size.

Continuing laboratory studies of small "steady state" fires fed by wooden-crib fuels show radiative and convective heat to be about one-fifth and two-thirds of the total energy output. Much of radiated heat is lost to distant surroundings though some is effective in preheating new fuels near the fire edge, thus contributing to the fire spread. Most of the convective heat, on the other hand, is converted to kinetic energy producing updraft velocity above the fire, and thus affecting the fire intensity.

Spotting ahead by fire brands is often associated with severe fires. Experiments at Madrid, Spain under PL-480 contract, are giving information on this complex phenomenon. Marble-sized wood spheres ignited in a wind tunnel have been weighed continuously through an initial flaming and subsequent glowing life. The air drag

on the spheres was also recorded during the process. From these data it is possible to compute the maximum distance these brands could start new fires if thrown out of the convection column at different heights above ground. Other materials and shapes are also to be investigated.

b. Fuel chemistry. Fuels are the source of the energy released by combustion. Their chemical characteristics thus have major effects on combustion. Sphagnum moss fuel contains 1.95 percent volatiles extractable with ether, western white pine needle litter 4.38 percent, and ponderosa pine needle litter 8.26 percent. In ignition tests with radiant heating in the absence of a pilot flame Sphagnum moss ignites first. The other two follow in the general order of their volatile contents when differences in fineness are taken into account. This is one of the important factors explaining the high susceptibility of rotten wood and decomposed duff to ignition by glowing embers.

c. Fuel moisture. Fuel moisture variations influence how much and at what rate potential energy is converted to heat energy by combustion. Fuel moisture content and rate of forward spread of fire have been shown to be very closely related and combustion chamber tests with pine needle litter fuels relate this in turn to both flame depth and flame residence time. The same tests showed the flow of radiant energy in the direction of flame spread to decrease about linearly with increasing moisture content to 11 percent, with an accelerated decrease at higher moistures.

Moisture content of live gallberry, redbay, swamp cyrilla, and switch cane - Southeastern lowland brush species - fluctuates significantly with time. Periods of lowest vegetative moisture content coincide with seasons of greatest fire occurrence.

Deadening inferior trees in Missouri to improve hardwood timber stands builds up fire hazard. It takes about 10 years of natural deterioration for 80 percent of hickory, blackjack oak, and black oak trees less than 11 inches diameter and white oak and post oak trees less than 7 inches diameter to fall apart.

Tracing the interaction of factors affecting the flammability of heavy slash fuel left after logging is underway in the Pacific Northwest. Temperature and moisture content of outer layers of logs vary widely with depth, angle of exposure to the sun, and from one log to another. Light rain greatly increases moisture to a half-inch depth on the top and sides of logs. This moisture evaporates in 2 summer days.

2. Fire Prevention

a. Man-caused fires. To be effective, fire prevention techniques must be accurately aimed at the people who visit our forests. What are these people like? Respondents in a 2-percent mail survey of 680,000 licensed hunters in California show: Hunters are 93 percent male; their average age is 37.4 years, with 80 percent under 50; 86 percent live in towns smaller than 250,000, but in which only two-thirds of Californians live; 36 percent are in skilled-semi-skilled and 18 percent in professional-managerial occupations; their IQ is relatively high.

b. Lightning-caused fires. Project Skyfire is measuring the characteristics of Northern Rocky Mountain thunderstorms. Short life is common--half of storms last 30 to 90 minutes, with 15 percent lasting less than 30 minutes. Half of the storms produce 10 or less discharges to the ground. The 5 percent of storms that produce

100 discharges per storm account for more than one-third of the discharge total in all storms. During a 4 year period, 50 percent of storms produced less than 0.1 inch of precipitation per storm. An additional 20 percent produced 0.1 to 0.2 inch of precipitation.

Lightning damage to trees, measured in Montana, is proportional to tree size, both diameter and height.

During 2 seasons of cloud seeding in one test area, 38% fewer lightning strokes were recorded on seeded days than on unseeded days.

c. Fuel-breaks. By managing the quantity and arrangement of fuels on strategic areas, the risk of severe fires can be reduced and better opportunities for controlling fires can be maintained. Regrowth of cut or burned chamise is effectively controlled in Southern California by low volume broadcast applications of 2,4-D. But treatments tested to date fail to prevent oak sprouting.

Annual rye grass continues to look good for revegetating bare areas; stands averaging 11 percent cover in 1961 formed a dense cover on good sites in 1962.

3. Fire Control Systems and Methods

a. Detection. Tests of an airborne infrared scanner continue in Montana. Mapping of "going" fires through darkness and smoke is operationally feasible with this instrument. Small fires can be "discovered" with the scanner, but in heavy timber stands the success score is low indicating a need for improving the equipment.

b. Fire danger rating. From a 25 year study in Idaho of variations in the moisture content of large logs, the principal factors involved in the gain and loss of moisture are moisture content at the beginning of a wetting or drying cycle, amount of precipitation, log diameter squared, hours of precipitation, and day length.

In the Northeastern States fires show notable uniformity in rate of enlargement in 12 of 15 major fuel types. The rate by individual types differs less than 15 percent from the mean rate for the 12 types combined. The mean rate is closely correlated with fire danger ratings.

Evaluation of the spread index being developed for nationwide use indicates that in the northeastern and southeastern regions the spread index can be substituted, with considerable gain in sensitivity, for the regional burning indexes now used.

c. Fire suppression. Field tests of fire retardants in California support earlier laboratory findings that thickened solutions of diammonium phosphate and ammonium sulphate are probably superior. Southern Forest Fire Laboratory experiments show that small quantities of four industrial gums --- carboxymethyl cellulose, guar gum, sodium alginate, and a polysaccharide --- effectively thicken diammonium phosphate. Attapulgit and bentonite clays are also effective thickening agents when used in sufficiently large amounts. Quantity required is the principal disadvantage.

Water thickened to the consistency of light motor oil with sodium alginate or sodium carboxymethyl-cellulose chloride is more effective than plain water for direct suppression of fire with pumps.

Fire research for the fifth consecutive year participated in a national fire behavior training school, this year devoted to Department of the Interior agencies. The purpose is to develop the ability of fire suppression strategists to integrate the fundamentals of ignition, combustion, fuels, weather, and topography into predictions and interpretations of fire behavior.

4. Use of Fire

- a. Direct fire effects. Understanding of fire intensity required to do specific land management jobs is urgently needed.

A survey of 27,000 acres of prescribed-burned Arizona ponderosa pine land points up that 77 percent of the land either did not burn or burned lightly by fire of ineffective intensity. Growing conditions were improved for 3.5 percent of potential crop trees. On the other hand, 10.9 percent of potential crop trees were killed and an additional 8.1 percent were damaged. That benefits exceeded damages is questionable.

Repeated prescribed-burns in palmetto-gallberry areas of the southeastern coastal-plain progressively reduce the quantity of fuels, but do not enlarge the number of plants killed. But combination of burning followed by a chemical spray is reasonably effective for killing both palmetto and gallberry plants.

- b. Techniques for prescribed burning. Managing fire intensity is necessary for the practical use of fire as a tool. Through field trials in California a promising method has been developed for disposing of slash from thinning young pine stands. Slash is piled, sprayed with an asphalt emulsion, and burned during wet weather when fire intensity is low. Sprayed piles burn when unsprayed piles and vegetation to be protected are too wet to burn.

To lower the risk of prescribed fires escaping control, in Arizona a technique for chemically desiccating chaparral vegetation and burning when untreated vegetation effectively resists fire is proving feasible.

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B. FOREST INSECT RESEARCH

Problem

Insects are among the most destructive of all the agents affecting the forests of this country. Each year they not only kill, weaken, degrade, or reduce the growth of vast quantities of valuable commercial sawtimber but, also, of large volumes of smaller-size timber. During periods of outbreaks, which occur frequently in many parts of the country, losses are much more severe, often bordering on the catastrophic. Losses are not confined to timber alone: watersheds and wildlife habitats are impaired and fire dangers are increased. Insects also damage or destroy the seeds and cones of trees, thereby jeopardizing the success of seed orchards and natural regeneration programs; they infest browse plants on forest-related ranges, thereby lowering their carrying capacities for livestock and big game; and they damage or destroy huge quantities of forest products, such as logs, lumber, and pulpwood each year. More information is needed on the causes of forest insect outbreaks; on the development of long-lasting silvicultural and biological control methods; and on the development or improvement of chemical controls that can be applied economically and without undue hazard to fish and wildlife.

Program

The Department has a continuing long-term program involving forest entomologists, insect ecologists, insect physiologists, insect pathologists, microbiologists, and photo interpreters engaged in both basic and applied studies directed toward the development of safer and more economical and effective methods of direct and preventive control of forest insects. Research is underway at the 10 Forest and Range Experiment Stations, Forest Products Laboratory, and Beltsville, Maryland Forest Insect Laboratory. The program is cooperative with various universities, State Experiment Stations, industries, other Federal and State Agencies, and Canada Department of Agriculture. The University of Connecticut assists in studies of bacteria in insects; Brookhaven National Laboratory, in studies of male sterilization of the gypsy moth by gamma irradiation; New York State Museum and Science Service, in ecological studies of the gypsy moth; University of California, in studies of insects affecting seeds and cones of Douglas-fir; National Park Service, of lodgepole needleminers in Yosemite National Park; Ohio Agricultural Experiment Station, studies of the locust borer. Agricultural Research Service cooperates in introduction of insect parasites and predators from abroad.

PL-480 projects are underway in Finland, Poland, Spain, Pakistan, Brazil, Colombia, and India on forest insects, with emphasis on the introduction of parasites and predators of important species.

The Federal scientific effort devoted to research on forest insects totals 81 man-years per year. The scientific effort by PL-480 researchers totals 55 man-years per year.

Several chemical companies supply materials for testing as systemics, and for control of wood products insects. Weyerhaeuser Timber Co. conducts research on insects affecting Douglas-fir. The University of Wisconsin studies

plantation insects; University of Connecticut, the gypsy moth; and University of Michigan, borers in aspen.

Progress

1. Biological Control

It is the general consensus that populations of most native forest insects are held to sub-economic levels by their natural enemies, such as parasites, predators and disease pathogens. Even where outbreaks occur, populations sooner or later are brought back to normal levels by these agents, even though no direct control action is taken. Introduced insect pests may become extremely destructive because of the absence of natural enemies. Here, it is often possible to remedy situations by introducing these agents into infested stands from the native homes abroad of these pests. It has been found possible to secure control of some insects through interference with their reproductive capacities. Some biological control factors such as viruses and bacteria can be formulated into sprays and applied to control active infestations of certain insects. Generally speaking, biological control is cheaper, safer, and longer-lasting than conventional methods of insect control.

a. Insect parasites and predators. The parasite, Orgilus obscurator, originally introduced from Europe to assist in control of the European pine shoot moth is now fairly widely distributed in pine plantations in Michigan as a result of additional colonization attempts. It was also recovered for the first time last year in Ohio. It appears that Temelucha interruptor another European species of the shoot moth has also been established in Michigan.

In 1960, colonies of the parasite, Agathis pumila, were collected in larch casebearer infested stands of larch in New England and shipped to Idaho for release in stands of western larch newly-infested by the casebearer. This year the parasite was recovered at one of the colonization sites. This indicates that it has become successfully established and offers promise of assisting in controlling populations of its host in the newly-infested stands.

So far, 22 species of insect predators of the balsam woolly aphid have been collected in Europe and the Far East and introduced into infested stands of true firs in the Pacific Northwest. To date, five species, all from Europe, have been colonized successfully. Two of these are beetles, Laricobius erichsonii and Pullus impexus; and three are flies, Aphidoletes thompsonii, Cremifania nigrocellulata, and Leucopis obscura. Two of these, L. erichsonii and A. thompsonii, have been found capable of developing fairly large populations and are spreading moderately well from points of release. The latter appears capable of spreading even where aphid populations are low.

Most of the same species of predators of the balsam woolly aphid introduced into the Pacific Northwest have also been introduced into aphid infested stands of Fraser fir in North Carolina. Recent studies indicate that at least four species (L. erichsonii, P. impexus, Aphidecta oblitterata, and Aphidolites thompsonii) have been established successfully. Of these, L. erichsonii looks most promising at this time. The program has been underway only since 1959, however, and it is too soon to tell what will happen.

The role of native predators in control of the balsam woolly aphid in the Pacific Northwest has also been studied for the past three years. Results indicate that

at least 26 species of arthropods are associated with the aphid; and that at least 18 of these feed on it. The most important ones are four species of syrphid flies, Cnemedon rite, Syrphus vitripennis, S. opinator and Metasyrphus lapponicus. So far, however, they have not been found to significantly affect aphid populations. The trouble seems to be that they are general feeders and show no particular preference for the balsam woolly aphid. Similar studies of native predators of the aphid in Fraser fir stands in North Carolina indicate that while they may kill fairly large numbers of their hosts they are incapable of preventing aphid populations from increasing. In this area, it appears that the life cycles of predators and the aphid are too poorly synchronized for the predators to exert significant control.

Progress was made in studies on the mass rearing of parasites of forest insects in the Northwest. The parasite, Coeloides brunneri, an important enemy of such destructive insects as the Douglas-fir beetle, was induced to lay eggs by confining females in small cages fitted with balsa wood bottoms, in which longitudinal grooves were cut. In other studies, it was shown that photoperiod and temperature are important factors influencing its development. For example, long days (16 hours or more of light) favored continuous development; whereas short days (14 hours or less of light) resulted in diapause, or arrested development. High temperatures also favored continuous development. Itopectis 4-cingulatus and Apechthis ontario, pupal parasites of tree defoliating lepidopterous insects, also were reared in the laboratory on the greater wax moth, Galleria melonella. These findings are important in that they offer promise in the year-round rearing of parasites for study purposes and in mass rearing of them for liberation in infested stands.

Progress was made in recently initiated studies of parasites of the spruce budworm in the Southwest, an area where practically no information on these enemies of the budworm is available. Here, studies of fifth-instar budworm larvae and pupae collected in six different areas revealed that parasitic Hymenoptera emerged from 20.9 percent of the larvae and 3.4 percent of the pupae; and parasitic Diptera from 1.3 percent of the larvae and 12.4 percent of the pupae. Information of this type is basic to an understanding of the causes of outbreaks of the budworm in the region; also of the abrupt declines of many of the outbreaks which occur there.

b. Parasitic mites. In addition to insect and nematode parasites, several species of mites are also important parasites of insects. Studies of the southern pine beetle in southeast Texas have revealed that eggs, larvae, and pupae are frequently destroyed by nymphs and adults of an acarid mite of the genus Thyreophagus, which feed voraciously upon their prey and devour all but the larval head capsule or other sclerotized parts. Apparently sound larvae and pupae placed near mites in culture, were destroyed within 24 hours. The importance of this mite in controlling outbreaks of the beetle remains to be determined.

Young females of a pyemotid mite, probably of the genus Pediculoides, seek out southern pine beetle larvae and pierce them with their mouthparts. As they feed, the abdomen becomes enormously distended and eggs develop and hatch within the swollen bag. When the young are born, they are sexually mature. At this time, young male mites cluster about the genital opening of the mother and fertilize the young females as they emerge. A single female mite may give birth to over a hundred mites, after which her body collapses and disintegrates.

These mites also fed in the laboratory on immature stages of Ips avulsus, another important bark beetle pest of southern pines.

c. Parasitic nematodes. Two important species of parasitic nematodes (Parasitylenchus elongatus and Parasitylenchus new species) were discovered infesting the fir engraver beetle, a serious pest of white fir in western United States. Studies showed that female beetles infested with the nematodes lay no eggs; and that infested male beetles are sterile. The life cycles of these two parasites are closely synchronized with that of the beetle, and infested beetles carry the nematodes with them when they fly to new host trees. Here they infest the progeny of noninfested beetles. Parasitized beetles construct short galleries--no more than an inch in length--before they are killed by the nematodes. The free-living stage of the nematode is deposited in these galleries. Following fertilization, female nematodes migrate and infest beetle larvae produced from non-parasitized parents. Males of both nematodes are free living and are found only in the egg galleries of the beetles.

Another nematode, Neoaplectana sp., killed the Douglas-fir beetle when it was applied directly to the beetle in the laboratory. So far, efforts to get the nematode to invade beetle galleries when applied to the surface of infested logs have been unsuccessful.

d. Insect Pathogens. There are several pathogens among the viruses, bacteria, and fungi which show promise for controlling pest species of forest insects. Some are host-specific; others attack and kill insects of many species.

An exploratory study of the phagocytic activity of blood cells was made in the Pacific Northwest, as a basis for identifying the defense mechanisms of insects against infection by microbial pathogens. India ink particles and virus inclusion bodies (polyhedra and granules) were injected into the last instar larvae of the army worm, Pseudaletia unipuncta. Results showed that both the India ink particles and virus inclusion bodies were almost completely removed from the hemolymph within 30 minutes after injection. Phagocytosis was carried out predominantly by micronucleocytes, occasionally by macronucleocytes and rarely by transitional prohemocytes. The micronucleocytes were capable of phagocytosing repeated dosages of capsules and developed close resemblance to the "luminescent cells" that appear in the blood of granulosis-diseased caterpillars.

A granulosis virus disease of the green form of the spruce budworm, Choristoneura fumiferana, appeared to be rather virulent in laboratory tests. Observations and studies of this virus are being continued.

Studies indicate that the bacterial insecticide, Bacillus thuringiensis, may be an effective material for controlling the lodgepole needleminer in California. In the Pacific Northwest, the hemlock looper, Lambdina fuscicollis fuscicollis; black-headed budworm, Accleris variana; spruce budworm (green form), C. fumiferana; pandora moth (larvae), Coloradia pandora; and oak looper, Lambdina fuscicollis somniaria, have also been found susceptible to this material.

A spore-crystal concentrate of B. thuringiensis was field tested against the gypsy moth in New York. Rates of from one to 4 pounds of Bt in both oil and water diluents were applied by Stearman aircraft against second and third instar larvae. The oil formulations gave poor control, and there was considerable

settling out of the material in the storage and mixing drums. Water formulations were more effective and easier to handle.

Extracts from the foliage of several species of trees have been found to inhibit the growth of *B. thuringiensis*. In contrast, a material that stimulates growth of Bt was also found in certain foliage. Recent studies show that dimethylformamide is an efficient solvent for extracting the antibacterial material found in pitch pine foliage.

Studies were made with several thin-layer chromatographic solvent systems in an effort to separate the inhibitory and stimulatory substances from the other tree species in Dimethylformamide extracts. Studies indicated that both substances are stable over a wide temperature range, at least for short periods of exposure. Extracts from Norway spruce, and Virginia and pitch pine foliage showed the same degree of inhibition and stimulation after one year of storage (either in the liquid state or dried on filter paper) as when they were fresh. These antibiotic materials have been found in foliage collected at all times of the year.

Recent studies of dying laboratory colonies of subterranean termites in southern Mississippi revealed that the dead insects were completely covered with a sporulating fungus. This fungus was isolated, grown in pure culture, and identified as *Aspergillus flavus*. As far as is known, this is the first report of this fungus being associated with termites, although it is known to affect many other insects.

e. New Approaches to insect control. In a study of the use of sterile males to reduce locust borer populations it was found that the chemical metepa (tris 2-methyl - 1-aziridinyl) phosphine oxide) is effective in reducing the viability of eggs from treated adults. Insects that were treated by allowing them to drink the chemical in sugar water, laid 96 eggs, only 12 of which hatched. Furthermore only 6 of the 12 larvae survived. An equal number of untreated insects laid 64 eggs, producing 64 larvae. In another study using females already mated, the 1 percent metepa treatment completely prevented any viable eggs from being produced.

When fourth and fifth instar gypsy moth larvae were exposed to gamma irradiation (2,500 r) at the Brookhaven National Laboratory, spermatogenesis was adversely affected and morphological aberrations attributable to treatment appeared among adults that eventually emerged. Egg production and viability were also reduced. Because of these crippling defects among the adult males, irradiation of larvae may not be a feasible approach to a control program utilizing the sterile-male release technique.

Studies in California to determine the cause for resistance of certain pines to bark beetles have shown that certain resin vapors and terpenes are toxic to the insects, and that the toxicity varies depending on the species of beetle involved. In more recent studies utilizing gas chromatography, six of seven ponderosa pines phenotypically resistant to the mountain pine beetle were found to contain resin having a rather high proportion of the terpenes delta³ - Carene plus limonene. It remains to be determined if they are indeed responsible for the resistance of these trees to the beetle. Recent studies in Georgia indicate that accelerated resin crystallization in loblolly and shortleaf pines attacked by larvae of tip moths is a factor contributing to the resistance of these two pine species to damage by these insects.

f. P. L. 480 Projects. These projects in biological control of forest insect research are underway in Poland, Spain, Pakistan, Finland, and India. Major emphasis is on biological control of important insect pests introduced into this country from abroad. This work is conducted in cooperation with Entomology Research Division, ARS. The Commonwealth Institute of Biological Control also cooperates in the work in India and Pakistan.

(1)-POLAND

a. Studies in the development of improved strains of forest insects. Progress is being made in efforts to determine possibilities of developing more effective strains of parasites of important forest insect pests. Colonies of a sawfly parasite, Dahlbominus fuscipennis, collected from 10 different regions in Poland are being investigated.

b. Insects noxious to young stands of pine. Results of these studies may be helpful in further efforts to introduce effective parasites into European pine shoot moth infested plantations in this country.

(2)-SPAIN

a. Study of parasites, predators, and diseases of the gypsy moth. Natural control factors occurring in Spain but not present in this country are being investigated to determine possibilities of introducing effective ones into gypsy moth infestations in this country.

(3)-INDIA

a. Natural enemies of Chermes spp. attacking silver fir and spruce. Studies are being made of the biologies of several promising species of predators of the balsam woolly aphid. Colonies of some of these predators have been shipped to this country for study and liberation.

b. Parasites of the gypsy moth. Surveys are being made in several regions in India to locate infestations of the gypsy moth and to determine species of parasitic and predaceous insect enemies of the species. Emphasis in future work will be on identification of species, in evaluating their control effectiveness, and in shipping colonies of promising ones to this country for liberation in gypsy moth infested stands.

(4)-PAKISTAN

a. Predators of species of Chermes (balsam woolly aphid). Studies are being made of the biologies of several species of promising predators of the balsam woolly aphid. Colonies of some species have been shipped to this country for study and liberation.

b. Natural enemies of insect pests of West Pakistan forests. Because many of the genera of trees in the United States are also found at elevations above 5,000 feet in West Pakistan, insect pests of these trees in the latter country are being collected and identified. Work is also underway to identify parasites, predators and pathogens that attack important pest species. Results of this study could be of value to this country if some of the pest species were accidentally introduced into our forests.

(5)-FINLAND

a. Orienting stimuli guiding insect pests of forests to suitable trees. The objective of these studies is to determine the factors responsible for the attraction of certain trees to insects.

2. Chemical Control

Many species of forest insect pests cause considerable damage despite efforts to reduce or prevent high populations by means of biological or silvicultural methods. Until such time as these methods are developed or improved, it will be necessary to continue to use insecticides to prevent intolerable losses.

a. Systemics. Young cottonwoods can be protected during the first year of growth from the twig borer, *Gypsonoma hainbachina*, by dipping cuttings prior to planting in carbon dust containing 44 percent of phorate (Thimet), a systemic insecticide. Additional protection is provided by making supplementary applications of the insecticide in granular form as a side dressing during the second and third growing seasons. At the end of the fourth growing season, 32 trees treated in this manner contained 0.79 cord of pulpwood while 32 untreated trees contained 0.49 cords. Heights and diameters of treated trees averaged 45.6 and 6.3 inches, respectively. By way of contrast, heights and diameters of untreated trees were only 42 feet and 4.9 inches, respectively. Differences between the two groups of trees were even more striking when the greater amount of crookedness, forking, branchiness, and other malformations that the twig borers and other insects caused in the untreated trees are considered.

Laboratory studies were made with four systemic materials -- zectran, HRS-1422, SD 3562, and CL 43064 -- against the gypsy moth in the Northeast. Concentrations of the toxicants were equivalent to 1 lb. and 0.5 lb. per 2 gallons of liquid. Under conditions of the test, all materials except HRS-1422 gave a high degree of kill. The materials were also studied under field conditions. Applications were made to small oak sprouts at two times: (1) prior to appearance of the leaves and (2) approximately two weeks later when the leaves were 1/2 to 1 inch long. When the leaves were fully developed, samples were brought in to the laboratory and gypsy moth larvae were placed on them. A higher mortality occurred on leaves sprayed when 1/2 to 1 inch long. Differences in effectiveness among materials were significant only with the young (instar I) larvae -- with SD 3562 proving most effective. Both concentrations of the toxicants were equally potent.

b. Fumigants. Methods were developed for the atmospheric fumigation of the European pine shoot moth with methyl bromide in commercial and forest nurseries. Studies revealed that fumigation of an entire small commercial nursery is feasible in the Puget Sound area of Washington during late fall. All treatments using ground tarps under chambers resulted in 100 percent shoot moth control. Tree damage from fumigation was minor.

Studies were also made on ponderosa pines in an uninfested forest nursery to determine the susceptibility of seedlings of this species to methyl bromide damage. Damage from winter fumigation to 1-0, 2-0, and 3-0 stock in seedbeds was not detectable where wet soil was used as a gas seal; also damage to baled stock fumigated at monthly intervals from December to April, and held from zero to three months in cold storage, was minor.

c. Conventional sprays. Helicopter application of 1/4 and 1/2 pound of malathion in 1 gallon of fuel oil per acre gave 86 and 94 percent control, respectively, of the spruce budworm on the Rio Grande National Forest, Colorado. This compared favorably with a 95 percent kill obtained with DDT applied at a rate of 1 pound in 1 gallon of fuel oil per acre by fixed-wing airplanes and helicopters.

Studies in the Pacific Southwest show that malathion sprays, applied against the moth stage of the lodgepole needleminer will provide a high degree of control for at least four years. Studies in sprayed areas indicate that spraying with malathion did not materially reduce the control effectiveness of needleminer parasites.

Insects frequently destroy a high percent of the cone and seed crops of Douglas-fir. Successful forest genetics and tree-breeding research require a high degree of protection of the cones and seeds of this species from insects. A study was made in a seed orchard on the Olympic National Forest in Washington to control one of the more important insect pests, the Douglas-fir cone midge (Contarinia oregonensis) with three chemical sprays - Sevin, Guthion, and benzene hexachloride. The chemicals were applied from the ground with a backpack motor-driven mistblower. The results were inconclusive, but they did indicate that Guthion was the most effective of the three insecticides. It was also demonstrated that the back-pack mistblower is an efficient device for spraying open-grown trees up to about 20 feet tall.

Present studies of the control of seed and cone insects in the South are giving greater attention to insecticides of low toxicity to man and other animals and to insect pathogens which might be used in biological control. Two carbamate insecticides, Zectran and Sevin, were found to be completely effective in killing larvae of the coneworm, Dioryctria abietella when applied to infested cones at concentrations between 0.75 and 1.0 percent in laboratory screening tests. Thuricide, a commercial preparation of Bacillus thuringiensis, also gave encouraging kills of 60 percent of D. abietella larvae when applied at concentrations of 0.5 percent by weight in water suspension, in the laboratory.

DDT in fuel oil at concentrations of 1/2 and 1 pound per gallon, aerially applied at rates of 1 and 2 gallons per acre, was tested against the pine reproduction weevil in a pine plantation in California. None of the treatments were effective in protecting the trees from attack; reasons for their failure are not clear. Trees sprayed by hand with the 1 pound per gallon formulation were not attacked.

A BHC aqueous emulsion shows promise as a remedial control for the black turpentine beetle in stumps. Studies in Louisiana showed that spraying newly-infested stumps with either a 1.0 percent BHC aqueous emulsion, a 2.0 percent BHC aqueous emulsion, a 1.0 percent BHC aqueous emulsion plus aroclor, or a 1.0 percent BHC aqueous emulsion plus abitol gave effective control of the black turpentine beetle during initial stages of gallery construction in stumps.

Techniques were developed at Beltsville to study the distribution of water emulsion sprays on coniferous foliage following various types of application. Results point out the limitations of present procedures used to recover insecticide residues from plant tissues. In addition this study offers promise in helping to explain such phenomena as residual life, availability to insects, and potential hazards of insecticides applied to forest trees.

Four applications in the late fall, winter, and early spring of 1961-62 were made to individual white pine trees with combinations of lindane and Zectran with aroclor, using the portable mist blower, to determine their effectiveness in controlling the white pine weevil. Test weevils were placed in screened cages containing sample twigs taken from the treated trees. Results showed that the lindane-aroclor combination was significantly more effective in reducing feeding scars and in killing the insects than the Zectran-aroclor one.

Research in California to detect possible insecticide resistance in the western pine beetle and Ips beetles yielded suggestive but non-conclusive results. For example - in a comparison of topical applications of lindane and DDT to adult beetles, the LD50 ratios showed lindane 16.9 times more potent than DDT to Ips, and 3.9 times more potent to western pine beetle. Similar tests previously gave values of 27.7 and 7.3, respectively. Further study will be needed to determine the significance of these results.

In a test to compare surface and tissue deposits of insecticides in California, both surface and tissue deposits showed up favorably in protecting uninfested pine from bark beetle attacks. Lindane and dieldrin in doses ranging from 0.5 to 1.5 percent almost completely protected bolts "baited" to attract wild beetles for the 8-week period of the test. Attempts to force attacks on these same bolts were equally unsuccessful. Surface or tissue deposits of 1 percent lindane, sprayed on felled ponderosa and sugar pines, some of which were baited, both protected the pines equally well from Ips, western pine beetle, and mountain pine beetle attacks for 12 to 13 weeks. Protection ranged from 93 to 99 percent.

Recent studies in California have demonstrated that application of 1.5 percent lindane--diesel oil spray to the bark of infested lodgepole pines in June will kill 90 percent of mountain pine beetle brood beneath the bark. This percentage kill is considered satisfactory control. Cost of treatment averaged \$4.81 per tree -- about one-half the cost of penetrating sprays.

Spray tests conducted in California revealed possibilities for controlling the Douglas-fir cone midge at the time when the adults emerge from the duff. Oil solutions of lindane, dieldrin, and Sevin were applied to specially prepared blocks of duff artificially infested with midges. The dose was 1.5 pounds of insecticide in 15 gallons of oil per acre, and spraying was done with a spray chamber. All the materials tested gave significant control at the 5 percent level when compared with unsprayed checks, but only dieldrin and lindane were significantly better than oil alone. The best results were obtained with the lindane treatment which produced a reduction of 98.5 percent in the number of insects emerging from the duff.

3. Silvicultural Control

It has been demonstrated that damage by some insects can be prevented or reduced by means of various timber management practices such as removing high risk trees and changing stand composition and density. Development of such control practices requires a thorough knowledge of the biology and ecology of the insects involved. Past experience has shown that when silvicultural control can be applied, it is one of the safest, cheapest, and most effective methods of all for preventing or reducing forest insect-caused losses.

a. Barkbeetles - The 25th annual cruise of insect-caused mortality on the old-growth pine plots in northern California showed that the volume killed by bark

beetles in the sanitation-salvage areas was less than half that in the natural areas for the latest year of record. On the five natural area compartments, containing 470.9 acres, pine mortality in 1961 averaged 165.5 board feet per acre. On the ten compartments cut by sanitation-salvage between 1937 and 1951 and containing 859.2 acres, the mortality averaged 82.3 board feet per acre. The same compartments had 143.4 and 83.3 board feet per acre mortality, respectively, in 1960.

The 1961 pine mortality on one 5-acre and five 10-acre plots in old-growth stands which are part of a continuing study of tree crown characters indicative of susceptibility or "risk" to bark beetle attack, consisted of one Risk 1, two Risk 2, and three Risk 4 trees. The crown characters for each tree on these plots were first appraised in 1937, and have been reappraised at 10-year intervals since. In these studies, trees with characters indicative of high risk have been killed more often than those of low risk.

In a study of the susceptibility of fire-injured Douglas-fir to bark beetle attack, it was found that about 70 percent of the trees were attacked by the Douglas-fir beetle. This suggests that in salvage operations to control wood borers and bark beetles, fire-killed trees should be included along with other known kinds of insect-susceptible trees.

b. Defoliators. Recent studies indicate that stand characteristics appear to markedly influence the amount of damage caused by the spruce budworm in Minnesota. Low levels of damage were associated with overstories of nonhost trees (especially aspen), the absence of white or black spruce in the stand, and a high site index. Heavily defoliated parts of branches of balsam fir exhibit a proliferation of new shoots following heavy defoliation, a condition that is almost entirely lacking on undefoliated parts of the same branch.

It has been determined that the amount of staminate cone production by jack pine is greatly influenced by stand density. This may be an important finding in that it may lead to the development of a method of silvicultural control of this budworm, inasmuch as young budworm larvae prefer to feed on male flowers of jack pine.

4. Biology and Ecology

Knowledge of the biology and ecology of insects is prerequisite to their control, be it by direct or indirect methods. No two insects are alike in their life histories, habits, or behavior. No two react alike to the complex of environmental factors affecting them. No two have exactly the same feeding habits or nutritional requirements. Some have a wide range of hosts; others are confined to single hosts. Some are even more restrictive, requiring not only single hosts but those in particular degrees of vigor. Some are widespread in distribution; others much less so. Conditions conducive to outbreaks are recognized for a few species. The causes of outbreaks of others, many of which are extremely destructive, are unknown. Much of the above applies equally to the insect enemies of forest insect pests. Success in forest insect control hinges largely on the status of our knowledge of insect biology and ecology.

a. Barkbeetles. Daily air temperatures of 100° F. and above during July, 1962, along with drought conditions, slowed an outbreak of the southern pine beetle in East Texas. Mortality of late-larval through adult stages was widespread, apparently as a result of the high temperatures.

An accelerated program of thinning stagnated young ponderosa pine stands in eastern Oregon and Washington resulted in increased activity by Oregon pine Ips, an insect that commonly breeds in slash, but which occasionally causes severe mortality in young pines. Studies showed that two complete generations of this species, plus a partial third, were produced in 1962, an unusually cool year. Individuals representing a third generation were still in the larval stage when winter arrived. None were alive the following spring. It appears from this that this species can overwinter successfully only in the adult stage in Oregon. In further studies, it was observed that Ips attacks in the spring occurred in two well-defined surges, one in mid-April and one in early June. During both periods, air temperatures reached approximately 70° F.. Important findings in respect to Ips broods developing in slash were: (1) Slash laid down as early as December produced tree-killing broods the following season, (2) broods were larger in concentrated slash than in scattered, and (3) in instances where only two green trees were felled at the same time, they were not attacked. The latter finding suggests that this insect is attracted only by sizeable accumulations of fresh slash.

An artificial diet was developed in North Carolina for rearing southern pine beetles, Ips bark beetles, and flatheaded and roundheaded borers from second instar larvae through the adult stage. This makes it possible to mass rear the beetles under controlled temperature and humidity conditions.

b. Defoliators. Recent studies of the pinyon needle scale, Matsucoccus acalyptus, a serious pest of pinyon pine especially in recreation areas in the Southwest, indicate that it is most vulnerable to control at the time it lays its eggs.

Many of the eggs of the black-headed budworm, Acleris variana, which overwinter on needles of western hemlock or Sitka spruce in coastal Alaska, are removed by sliding snow and ice during the winter. In laboratory studies, it was found that a cold shock is needed to break dormancy of this insect, and that a rather long warm period (17-28 days) is needed after the cold shock before the eggs hatch. These findings help to explain why the eggs of this insect are able to survive in coastal Alaska. Because of the long period of chilling required prior to hatching, plus the unusually long period of warm weather needed following chilling, the eggs are prevented from hatching too soon during the spring.

In the Southern Appalachians, the elm spanworm lays its eggs almost exclusively on the undersides of branches. This habit is beneficial to the species inasmuch as normal hatching occurs only among eggs laid in the shade. The impulse to seek shady spots may also be of further benefit to the species in that it causes spanworm adults to migrate from heavily defoliated stands.

Laboratory studies in the Pacific Northwest reveal that larval development of the hemlock looper is slowest on western hemlock and most rapid on Douglas-fir. Field studies indicate that looper larvae do not move around very much in the early instars; but later on, some of those in the understory appear to migrate to the overstory. So far, no appreciable looper mortality from parasites or disease has been recorded until larvae were almost full-grown. Many larvae die from unknown causes. This is greatest on hemlock and Douglas-fir and least on Sitka spruce.

There appears to be a fundamental difference between the normal and green forms of the spruce budworm, both of which occur in Oregon, a condition that can be

detected with spectrophotometric methods. The significance of the green form, which is an abnormal one, is unknown. It is being investigated to determine if a better understanding of it would be helpful in developing better methods of control of the more widespread and highly destructive normal form.

c. Seed and cone insects. A total of 65 percent of 1,206 2-year-old red pine cones, collected from 10 seed-production areas in the northern Lake States, were infested by insects. The most common species were Conophthorus resinosae, Rubsaamenia sp., Laspeyresia toreuta, Eucosma monitorana, and Dioryctria spp.. Cones infested by C. resinosae and E. monitorana were killed, and seed loss was complete. Rubsaamenia sp. and Dioryctria spp. also often kill cones causing high seed loss. L. toreuta kills only those seeds in the cone which are actually fed upon. In one seed-production area, the entire cone crop was destroyed by the red pine cone beetle, Conophthorus resinosae.

A total of 43.6 percent of over 2000 white spruce cones collected in small areas in northern Wisconsin were also infested with insects. One species, Laspeyresia youngana, alone damaged 26.2 percent of all cones. Studies show that almost two-thirds of the seed in a cone infested with this insect are destroyed. Other important species were Pegomya anthracina, Dasyneura spp., Dioryctria spp.. All told, it is estimated that about 15 to 20 percent of the white spruce seeds were destroyed by insects in the study area.

In interior Alaska, an unidentified species of insect, observed for the first time in 1962, was responsible for the destruction of nearly 50 percent of the white spruce seed examined. The damage caused was similar to that caused by Pegomya anthracina.

The biology of the sugar-pine cone beetle in western white pine in California is similar to but distinct from that in sugar pine growing in the area. Further study will be needed to determine if this is due to a real difference in species or to a difference in habitat. Adult and immature stages of this insect die in cones that are exposed to direct sunlight on the surface of the ground. A high percentage of infested cones are aborted.

d. Plantation insects. High vigor pines growing on good sites in the Lake States sustained only a few European pine shoot moths and but little damage; whereas slow growing trees harbored high populations and were severely damaged. These findings are being used to draw up a guide for rating planting areas as to shoot moth hazard.

Under conditions of open terrain, and despite rainy weather which was unfavorable for flight, spread of the European pine shoot moth against prevailing winds in the Pacific Northwest was 200 feet. Cross-wind dispersal was somewhat less and with the wind negligible. The findings have particular value in helping to determine which pines should be fumigated or destroyed in shoot moth eradication programs.

e. P. L. 480 Project

SPAIN - Pests of poplars and preventive and curative methods of control.

This research is concerned with investigating causes of resistance in trees to attack by borers. Clones from various locations in southern Europe have been collected and planted for future study. Some information has been obtained on

the biologies of some of the more important insect species. One of these insects is the poplar and willow borer, Crytorhynchus lapathi, which was introduced into the U. S. many years ago and is now a serious pest.

5. Wood Products Insects

Insects that damage or destroy wood products cause heavy losses in this country each year. In spite of the fact that considerable progress has been made in past research in methods to prevent or control populations of these insects, losses are still severe.

a. Termites. In field tests near Gulfport, Mississippi, an emulsion of one of the currently recommended insecticides was applied on top of a 4-inch layer of washed gravel instead of to the soil beneath the fill. After 5 years, termites have failed to tube up through the treated gravel although they readily did so through untreated gravel. This knowledge will facilitate the scheduling of pre-treatment operations, since the chemical can be applied either before or after the fill material is put in place.

Soils treated 19 years ago with sodium arsenite and DDT are still giving complete protection to sap-pine stakes from termites. Sodium arsenite was applied as a 10 percent solution in water, at the rate of 5.6 pints per cubic foot of soil treated and DDT as an 8 percent solution in kerosene at the rate of 3.2 pints per cubic foot.

Chemical analyses of soil treated with heavy applications of DDT showed that at least 25 percent of the material was still present after 18 years. Plots from which the soil was collected were fully exposed to the weather for the entire period.

b. Powder-post beetles. Studies under simulated lumber storage conditions show that Lyctus powder-post beetle attack can be prevented for several years by dipping wood for short periods in various insecticides. Water emulsion treatments of gamma BHC were also found to be particularly effective in preventing ambrosia beetles from attacking green hardwood lumber. It can be applied in green chain vats in combination with sap stain preventives.

In recent studies at the Forest Products Laboratory, rough lumber was dip-treated with a waterborne chemical at the time of sawing and the lumber was then subjected to simulated kiln drying. Five prominent chlorinated hydrocarbon insecticides applied to green wood persisted through the heating and the residues were sufficient to prevent later infestation.

6. Survey Techniques

Studies are conducted to provide survey methods for those insect species where none now exist and to improve upon methods presently in use.

a. Aerial surveys. Recent research has shown that aerial observation and 70 mm aerial color photography are useful in assessing spruce budworm damage to white spruce and balsam fir stands in Minnesota. Photo interpreters have estimated defoliation with a correlation coefficient of .90 or better when compared with estimates made on the ground.

A multiple regression was developed for deriving stand volumes directly from color transparencies of aerial photographs of spruce and balsam fir killed by the spruce budworm in the Lake States. Cubic volume estimates were within +7% two-thirds of the time.

In photo interpretation studies, fir mortality resulting from stem attacks by the balsam woolly aphid has been correctly identified 93 percent of the time. In contrast, gouted trees were correctly identified only 71 percent of the time.

b. Ground surveys. Studies in California showed that radiography can be used to obtain estimates of western pine beetle populations in infested bark, and to follow brood development during the first and second generations. The radiographic method of estimating populations was 8 times faster and far cheaper than the old dissection method.

Radiography was also found to be a more rapid method of sampling populations of the southern pine beetle in the Southeast. Here, it was shown that only five minutes were required to x-ray a bark sample, process the x-ray, and count the insects on the radiograph. In contrast, it took 1-1/2 hours to dissect one 3"x6" sample. There was no significant difference in population estimates between the two methods when compared by the standard t-test.

An improved method for sampling populations of the European pine shoot moth in the Lake States was developed. It is based on the fact that the proportion or percentage of sample units infested is a good measure of shoot moth density. A sample unit may be a whole tree, or halves, or quadrants of trees. Counting of a sample unit is a far more rapid procedure than counting the insects infesting entire sampled trees.

In a study of the egg laying habits of the hemlock looper in the Pacific Northwest it was found that egg deposition was associated with the presence of moss, and was greater on vertical surfaces, such as boles, than on horizontal surfaces such as limbs. There was no substantial correlation between the number of eggs deposited on trees and the number found in samples taken at ground locations.

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C. FOREST DISEASE

Problem

Diseases occur in all parts of the country irrespective of land ownership, on all forest tree species, hardwoods and conifers alike, on trees of all ages from the seeds themselves to overmature forest veterans, and affect all parts of the tree from the root tip to the terminal bud and from the outer bark to the central pith. Other forest plants important to forage, recreational, and watershed values are equally subject to attack. These diseases are caused by a wide range of biotic agents such as flowering plants, fungi, bacteria, nematodes, and viruses and an equally diverse assortment of abiotic factors such as temperature and moisture extremes, nutritional excesses or deficiencies, and noxious substances in the atmosphere. Working singly or in combination these factors may induce disease causing death, loss of growth, deformity, lowered quality, or destruction of wood already formed in forest trees. In total, they cause as much loss in our forests as all other destructive agents combined, including fire, insects, and animals. In terms of volume, this growth impact amounts annually to 5 billion cubic feet of growing stock, including 20 billion board feet of sawtimber -- a loss almost equal to the annual cut of timber in the United States. In addition, many of these or other agents continue their destruction of wood products extracted from the forest to cause additional losses estimated at \$300,000,000 per year.

Program

The Department has a continuing long-term program of basic and applied research directed toward the solution of forest tree disease problems and the development of means for their control. The program is a national responsibility of the Forest Service and is conducted at 9 of the 10 Forest Experiment Stations, the Forest Disease Laboratory attached to the Washington Office, and the Forest Products Laboratory. Each of the Stations conducts research on a variety of diseases of especial importance in their geographic area of responsibility and may also have leadership for research on diseases of broader regional impact. The Lake States Station, for example, has primary responsibility for research on hypoxylon canker of aspen, the Central States Station for oak wilt, the Pacific Northwest for Poria root rot of Douglas-fir, the Intermountain for breeding western white pine for resistance to white pine blister rust, and the Southeastern Station for research on air pollution as a cause of forest tree diseases.

The Forest Service now devotes 70 professional man-years of effort to research in this area and has general supervision over another 16 man-years of foreign professional effort devoted to PL-480 projects abroad. Over one-half of the Forest Service scientists are plant or forest pathologists but to provide all of the talents required, especially for more basic research aspects, biochemists, ecologists, serologists, meteorologists, nematologists, physiologists, microbiologists, and soils scientists are also employed.

This research program is carried out in cooperation with other Federal, State, and local public agencies. Oregon State University, for example, provides mensurational assistance on the study of dwarfmistletoe growth impact on ponderosa pine; the Georgia Forest Research Council provides financial aid and the Georgia Forestry Commission labor, land, and equipment for research on fusiform rust and nursery diseases; Montana State University is working out the life history of Elytroderma deformans; the Universities of Missouri, West Virginia, and Pennsylvania State coordinate their researches on oak wilt with the Federal program;

and TVA and the Universities of California and North Carolina cooperate on the study of air pollutants.

Under PL-480 authority and funds, research programs supplementing and complementing domestic ones are under way in Finland, Italy, Poland, Spain, India, Taiwan, Brazil, Colombia, and Uruguay; some of these projects are designed to disclose native pathogens of special potential threat to North American forest tree species.

Industrial forestry organizations are also active in forest disease research and cooperate with the Forest Service program by freely exchanging research results, making their lands and timber available for study, providing technical consultation, and furnishing labor. Several chemical companies donate their products for experimentation; the Pabst and Upjohn Companies are especially active in this field. The Department of Defense supports substantially the research on the decay of wood in use as do several other major users of wood products and manufacturers of wood preservatives. Annual outside expenditures are difficult accurately to determine but are estimated to be equivalent to one-half the manpower devoted to this project by the Forest Service.

Progress

1. Seed and Seedling Diseases

a. Phomopsis blight of eastern redcedar. Contrary to published reports of earlier work, infection by Phomopsis juniperovora was readily obtained at Lincoln, Nebraska, when unwounded eastern redcedar seedlings were incubated at 24° C. and 100 percent relative humidity and inoculated with spore suspensions of the fungus.

b. Nursery soils and chemical controls. Soil samples were collected from 30 forest tree nurseries in 10 southern States and assayed for fungi. A total of 121 species representing 45 genera were isolated, including 16 phycomycetes, 11 ascomycetes, and 94 fungi imperfecti. Several fungi were found that had not been previously reported from the soil or were new to the United States.

Organic soil amendments were found, several years ago, to reduce damage by Fusarium in the Bend (Oregon) Nursery. Recent work has shown that these amendments considerably increase the abundance of Trichoderma spp., fungi capable of exerting biological control of soil pathogens. Fertility in the usual sense does not appear to be involved, since ammonium phosphate increases seedling growth but does not significantly affect either the disease or soil microflora. Results suggest that Fusarium control is effected by antagonistic soil fungi, and that a higher degree of control may be obtainable by further stimulating these fungi.

Nursery soil fumigation trials at two U. S. Forest Service nurseries in California demonstrated the tolerance of Douglas-fir seedlings to high dosages (600 lbs./acre) of methyl bromide. Disease and weed control plots showed that a mixture of 57 percent methyl bromide and 43 percent chloropicrin was much more effective than equal dosages of either compound used by itself.

Root lesion nematodes (Pratylenchus penetrans) damaged nursery stock of eastern redcedar, Rocky Mountain juniper, white spruce, and blue spruce in the Bessey Nursery, Halsey, Nebraska. Infestations were associated with nursery windbreaks of eastern redcedar. Both Dowfume MC-2 and Vapam gave good control, with the former better for spring planting and the latter better for late summer or fall.

Sclerotia of Macrophomina phaseoli were tested for thermal tolerance to obtain thermotherapy values for diseased nursery stock in California. Thermal inactivation of this important root-disease fungus was reached at 50° C. for 2 hours, 55° C. for 8-12 minutes, and 60° C. for 30-120 seconds. Thermal death range was shown to be more useful concept than thermal death point. Soil temperature was found to be the controlling factor in determining the part of the host attacked (root, hypocotyl, or cotyledon) by this fungus.

In greenhouse tests of seed protectant chemicals at Lincoln, Nebraska, thiram (a fungicide commonly used for damping-off control in pines) significantly reduced germination of ponderosa pine seeds when germination temperatures were 95 to 100° F.

Either Captan or Maneb applied at weekly intervals between June 15 and August 31 controlled a natural epiphytotic of Septoria leaf spot of sumac (Rhus trilobata) and buffaloberry (Shepherdia argentea) in an eastern Nebraska nursery.

c. Cone rust. Cone rust of slash and longleaf pine annually reduces the seed crop by about 20 percent. Tests show that hydraulic spraying of slash pine trees with ferbam every five days during the flowering season will give excellent control of the disease. An aerial spray test in a seed production area also gave promising results for control. The chemical showed no adverse effects on the fertilization process or seed-set on sprayed cones. Cone rust control recommendations based on these findings for use in pilot tests in seed orchards and seed production areas are being drafted.

d. Yellow birch seedling canker. Yellow birch is particularly hard to regenerate under the recommended selection system of northern hardwood management. Numerous yellow birch seedlings infected with a canker which girdles the stem and results in the death of the stem above it have been found in the Lake States. While this disease rarely kills entire seedlings, it does eliminate them from competition with surrounding vegetation by reducing their height and may be an important factor in regeneration failures of yellow birch. A species of Phomopsis has been isolated from the cankers and shown to be pathogenic.

e. Susceptibility of American trees to foreign pathogens. Seedlings of 9 species of important North American forest tree genera (Pinus, Picea, Pseudotsuga, Tsuga, Thuja, Tilia, and Quercus) from 32 provenances have been established from seed sent from the USA in 1960, in nurseries and plantations in 8 climatic zones in Poland to test their susceptibility to indigenous diseases. Similar projects have more recently been initiated in Brazil, Colombia, and Uruguay as part of an international effort to forestall importation of serious forest tree pathogens and insects. (PL-480)

2. Root Diseases

a. Fomes annosus root rot. Root rot data from a Southwide survey of 84,000 trees on 476 random plots were reported in detail last year. A digest of these data shows that annosus root rot is seldom a problem in thinned natural slash and loblolly stands, or in unthinned stands. Although losses were greatest in thinned planted stands, it is doubtful that one should recommend against thinning unless the history of a given area indicates a high root rot hazard, or stand values are unusually high.

While overall losses have been relatively low, the incidence of infection of white pine by Fomes annosus in North Carolina exceeds 50 percent in some stands. Losses result from butt rot, killing, windthrow due to root decay, and predisposition to attack by turpentine beetles. Damage was observed in both natural and planted stands. Infection of standing trees was primarily through root contact or grafts with roots of neighboring infected stumps. Conks of F. annosus appeared on stumps within two years after thinning. Spores were discharged throughout the year. Since the fungus can readily spread within an infected stand, and spores from fruiting bodies are uniformly available for infection of freshly cut stumps, annosus root rot can be expected to cause heavy damage in white pine stands where conditions are conducive for disease development.

Freshly cut stumps are often considered to be one of the focal points for initial infection of a stand by Fomes annosus. Five hundred freshly cut stumps of Pinus echinata were treated in the Southeast with several types of inoculum to evaluate relative rates of colonization and penetration. After three months, 86 percent of the stumps inoculated with mycelium in sawdust, 95 percent inoculated with a basidiospore suspension, and 97 percent inoculated with a conidial suspension were infected. Fifty-nine percent of the water check and 71 percent of the sawdust check stumps were also infected. Deepest penetration and largest percentage of stump volume colonized resulted from basidiospore inoculation. The mycelium inoculum gave the least penetration and colonization. This would indicate that basidiospores might be the most potent source of inoculum in causing natural infection of stumps.

One problem in studying Fomes annosus has been the inability of researchers to determine accurately the extent of fungal spread in the host tissue. In one method, infected wood is incubated for several days and then examined for the presence of the fungus on the wood surface. This method was compared to the standard pathological technique of making tissue isolations on a selective medium. Isolation on a selective medium revealed that a higher percentage of stumps was infected than did the incubation method. Furthermore, incubation at 70° F. indicated greater penetration of F. annosus than was indicated by the tissue plating method, while incubation at 60° F. indicated less penetration. These data indicate that the tissue isolation method is more accurate than the incubation method for both the presence of F. annosus and the extent of fungus colonization. In critical studies, tissue isolations on a selective medium should be used.

Attempts to isolate Fomes annosus directly from infected wood often fail because of swift colonization of the medium by fast-growing saprophytic fungi and bacteria. A peptone-salts medium containing pentachloronitrobenzene, streptomycin, lactic acid, and ethyl alcohol was developed which allowed normal development of F. annosus but inhibited the growth of associated organisms. Use of this selective medium permits critical determinations of host tissues invaded by the fungus.

Until 1961 only two cases of Fomes annosus root rot had been reported in Missouri. A survey on state and federal land in southern Missouri disclosed the disease widely distributed in thinned plantations of shortleaf pine but less common in thinned natural stands. The disease occurred on 7 of 13 National Forest Ranger Districts and on both State Forests examined. A study was therefore made of the relative effectiveness of several chemicals as stump treatments to control Fomes annosus root rot. Stumps were cut and immediately treated with the chemicals, after which they were sprayed with a concentrated spore suspension of the fungus.

In this test, ammate and urea gave 100 percent protection, ammonium fluoride 90 percent, pentachlorophenol 80 percent, and creosote 60 percent. Fomes annosus was present in 90 percent of the non-treated checks.

Two pine and two spruce stands have been selected for exhaustive study in Poland, with heavy and light Fomes annosus and Armillaria mellea root rots, respectively. Research is under way to determine the role of soil saprophytes in controlling these two root pathogens. (PL-480)

b. Poria weirii. Studies of Poria weirii clone patterns in infected stands in the Pacific Northwest have practically confirmed the hypothesis that the fungus can survive for several decades in buried wood residues and then spread vegetatively into living roots of the new stand. Clone studies have also shown that a large majority, and probably nearly all, of the infection centers in present-day stands are "holdovers" from infections in preceding stands, rather than totally new centers originating from spore infections in present stands. This work indicates that the best chance for effective control is in breaking the vegetative persistence of the pathogen, rather than in prevention of infections by spores.

c. Mycorrhizae. Exploratory field and laboratory work was begun on the etiology of decline and mortality in marginal ponderosa pine, pinyon, and juniper in New Mexico. Special attention was devoted to the possibility that plant parasitic nematodes or inadequate mycorrhizae development may be associated with drought and generally unfavorable environmental conditions. Nematodes recovered in preliminary samplings to develop techniques included 9 genera of plant parasitic nematodes, 2 genera of suspected plant parasites, 13 genera of saprophageous and free-living nemas, and a single genus of predatory nematodes. Isolations were made from 88 of 286 sporophores of suspected mycorrhizal fungi and 58 of these produced colonies other than common contaminants. From a total of 464 isolations from mycorrhizal root tips (280 ponderosa pine, 88 pinyon, and 96 juniper), 195 produced colonies other than common contaminants.

d. Littleleaf of shortleaf pine. Littleleaf of shortleaf pine is the most serious disease of this species in southeastern United States. It has now been discovered in New Zealand on shortleaf pine under conditions very similar to those where the disease is serious in the United States.

Studies on the distribution of Phytophthora cinnamomi, the cause of the littleleaf disease of shortleaf pine, revealed that it occurs in Coastal Plain and Piedmont soils outside the littleleaf belt as far north as Maryland. It was isolated for the first time from littleleaf sites in Tennessee and Kentucky. The fact that the fungus was isolated from areas where the disease is not prevalent supports the conclusions from previous studies that certain site factors, as well as the fungus, must be present to produce disease symptoms.

A survey was made to determine if nematodes, as well as the fungus Phytophthora cinnamomi, were involved in causing the deterioration of the small feeder roots that is typical of littleleaf-diseased trees. Since there were no significant differences found between the nematode populations on littleleaf-diseased sites and healthy sites, it must be concluded that nematodes probably do not play an important role in causing the disease.

3. Stem Diseases

a. Native rusts of conifers. The history of comandra rust infection of lodgepole pine in the Teton National Forest was studied on 20 randomized 0.1-acre dissection plots. Twenty-four percent of the living lodgepole pines bore trunk cankers and an almost equal number of trees had recently been killed by comandra rust. Infection apparently occurred 20 to 50 years ago. No trees had been infected within the last 10 years. This study and other surveys show that there has been little recent infection by comandra rust in the Rocky Mountain Region, but outbreaks 20 to 40 years old continue to cause heavy damage to lodgepole pine by killing the larger trees and causing spike tops.

First examination of large-scale tests of antibiotic control of comandra rust on lodgepole pine was made in 1962, one year after the study plots had been aerially sprayed. Most of the 4-acre plots had been sprayed with the semicarbazone formulation of cycloheximide at concentrations of 200, 300, and 400 p.p.m. at rates of 5 and 10 gallons of spray per acre. One plot was sprayed with 400 p.p.m. of the methyl-hydrazone formulation at 10 gallons per acre. No control was detected; both aecial and pycnial sporulation increased, and canker growth continued on nearly all trees whether treated or untreated. Similarly, no control could be detected on trees where these antibiotic materials had been applied as basal-stem treatments in July 1961.

Growth of 32 broomed Engelmann spruce and 33 broomed subalpine fir was compared with growth of paired healthy spruce and fir trees in six plots in the Rocky Mountain region. Height and diameter growth were significantly less in diseased spruce than in healthy, the rust caused up to 30 percent decline in current increment. No growth differences due to fir broom rust were significant, probably because the infections sampled were relatively recent.

Distribution and host records have been published for Cronartium comandrae, the C. coleosporioides complex, and Peridermium mexicanum. P. mexicanum causes a distinctive lobed, stalked gall, and should not be considered synonymous with any Cronartium species until the connection is proved. Nomenclature in the C. quercuum group was reviewed, and inoculations bearing on the possible relationship of P. cerebroides were reported.

b. White pine blister rust. Research findings of microclimatic relationships of white pine blister rust can be used to reduce losses from this disease and also reduce control costs in the Lake States. It has been shown how hazard of infection varies on different sites, the type of control needed on the various sites, and how suitable overstory crown canopies can reduce losses. Application of knowledge obtained in this research has already substantially reduced control costs by the elimination of direct control measures on areas where the microclimate is unfavorable for infection.

White pine blister rust is widespread and abundant on sugar pine in northwest California. In the central Sierra Nevada, it tends to occur in "pockets" in canyons and stream basins. Records of 14 infection areas near the southerly limit of the disease have been examined. Eight physiographic factors were computed for each study area. Canyon physiography and intensity of rust were markedly correlated. A records approach to prediction of future rust incidence in the central Sierra Nevada could be useful in planning control work.

Consistently effective and proven methods of antibiotic treatment have not yet been developed for controlling blister rust on eastern white pine. Research in the Lake States shows that under greenhouse conditions foliar sprays can be transported in the tree and can kill cankers. This indicates that there is promise of developing an effective and practical means for their use.

Field trials in western North Carolina, however, have given essentially negative results. Studies which included over 700 eastern white pine trees were established in 1959 and 1960 so that second- and third-year data are now available. To date there are no cankers on any of these 700 trees that have unquestionably healed following Acti-dione treatment. Throughout the test there has been less fruiting on cankers treated with Acti-dione; however, these cankers have in most cases continued to enlarge.

Tests of chemicals for the control of blister rust infections on host pines in California show that a practical measure of success can be achieved when it is possible to spray directly the site of infection. Oil-soluble organic fungicides such as orthophenyl phenol appear to be as good or better than antibiotics such as Acti-dione and Phytoactin.

Results of comparative biochemical analyses between western white pines resistant and susceptible to the blister rust fungus indicate no varietal differences in free sugars, amino acids, organic acids, chloroplast pigments, dry-matter, pH, ash content, or macronutrient minerals. In the case of phenolics, however, preliminary results indicate their involvement in resistance.

c. Fusiform rust. A histological study of fusiform rust galls on slash pine, conducted at Gulfport, Mississippi, disclosed that the parasite may occur in any stem tissue and cause pronounced tissue changes. The innermost extent of the fungus is marked by a layer of wood parenchyma which indicates the point of initial cambial infection. There is no evidence of inward spread in the xylem. Fungus hyphae usually grow by apical elongation. In order to maintain radial continuity in the wood, rust hyphae appear to elongate by intercalary growth at the cambium with hyphal and cambial growth synchronized. Probably one key to control lies in disrupting these fine physiological and morphological balances between fungus and host.

Fusiform rust has been considered as being almost always lethal to infected seedlings with galls at lifting time. However, in one study, two and one-half years after outplanting such seedlings in the South, 5 percent of slash and 10 percent of loblolly apparently had recovered from rust. Healthy tissue surrounded the original galls. Such individuals may be an additional source of genetic material in developing rust-resistant strains.

Many seed orchards have been established throughout the Southeast in order to produce seed from selected superior trees. About 20 percent of grafted pine seedlings in some of these seed orchards have fusiform rust galls at or near the graft union. Eventually most of these diseased trees will either die or be removed and replaced by uninfected grafts. In the establishment of large-scale seed orchards of grafted slash and loblolly pine in Georgia, procedures to avoid or reduce the amount of rust should take precedent over other considerations. Nursery-bed grafts and those made on potted stock offer means of control during the season the grafts are made. Other protective measures, such as chemical sprays, are essential during the early life of the grafted seedlings.

Five years of trials were completed in the South on the effect of antibiotics on fusiform rust. Commercial and experimental preparations, including cycloheximide and its derivatives, were tested in water and fuel-oil solutions or as emulsions at 2.5 to 600 p.p.m. Several thousand slash and loblolly pines were treated by (1) dipping roots of infected planting stock in water solutions or clay slurries, (2) spraying seedlings before and after inoculating with rust, (3) spraying the lower bole of infected saplings, and (4) brushing wounds formed when infected branches were pruned after branch galls had barely entered the stem. The results are discouraging. Either the antibiotics tried as therapeutants were ineffective at concentrations which did not damage the pines or the preparations did not penetrate the host in adequate amounts. Only when several applications were used as protectant sprays during the rust-infection season was appreciable control attained, and then less than that afforded by ferbam. Further empirical trials are not warranted.

d. Canker diseases. Fusarium solani was found to cause trunk lesions of swamp tupelo in Louisiana. So far the disease is not widespread. Inoculations of tupelos 1, 2, and 30 years old made during the dormant season resulted in cankers; all inoculation wounds made in April and August, i.e., during the active growth period, healed without cankering. Thus it appears that the causal fungus is only weakly parasitic and that the lesions are potentially important as a cause of degrade rather than tree mortality.

Fusarium solani also was consistently isolated from the margins of new cankers found on cottonwood growing on the Mississippi River batture from Bolivar to Issaquena Counties, Mississippi. The cankers consist of killed zones on the main stem. They may cover only a few square inches or may be large enough to girdle the tree. In one 20-year-old stand all trees were affected; 12 percent were broken off and 27 percent more were dead but standing. All infections seemed to have occurred in early 1961, when, for the first time in a decade, many of the areas were flooded to a depth of 5 to 15 feet. The spores of the fungus may have been distributed by flood waters and infected the trees through minor wounds. A survey from Vicksburg to Memphis showed that cankering was less prevalent in 1962 than in 1961. Cankers were most prevalent in the 15- to 25-year-old class.

Sweetgum lesions are widespread in bottom lands within 100 miles of the Gulf Coast, where it is common to find lower trunks disfigured by callus formations that develop over numerous small, storax-bleeding lesions. The fungus causing these lesions was identified as Botryosphaeria ribis. Inoculations in Alabama, Mississippi, and Louisiana proved the fungus to be pathogenic. Both intracambial and phloem inoculations resulted in lesion development. Isolates from both trunk lesions and twig cankers (which occur outside the lesion range) caused trunk infections. The disease does not kill but leads to significant degrade in butt logs.

During the past 2 decades a disease of unknown cause has destroyed several thousand acres of red pine plantations in the Upper Peninsula of Michigan. One of the symptoms is the presence of cankers on the affected trees. The only organism that can be consistently isolated from these cankers is the fungus Pullularia pullulans. Inoculations have shown that this fungus is not the cause of the cankers.

Aspen is the most extensive forest type in the Lake States region. Hypoxylon canker causes severe mortality in this type, and current losses are estimated to exceed 1,000,000 cords of wood per year. During the past year evaluation of progeny in an aspen breeding program has provided preliminary indications that

breeding for resistance to hypoxylon canker is not a simple matter. Polyploids appear to be as susceptible as diploids, and interspecific crosses have shown no unusual promise.

Preliminary research was started on the effects of bark moisture content on the pathogenicity of canker fungi on aspen and cottonwood in New Mexico. It was found that midsummer bark moisture coefficients were well below the 80 percent level that has been found to be critical for species of Populus in Canada. This was true even for trees growing on ditch banks where, presumably, they had access to abundant water. Pitch canker of southern pines is a destructive disease that could develop into a major problem. Nothing is known about the dissemination of the fungus or the means of infection. A study in the Southeast showed that a definite relationship exists between tip moth damaged slash pine seedlings and the incidence of pitch canker. It is suggested that the tip moth may establish an infection court for the fungus while feeding on the pine shoots.

e. Dwarfmistletoes. Although foresters are aware of the general abundance of dwarfmistletoes in northeastern Washington, no specific information is available to show the magnitude of the problem. Surveys were therefore made to provide information on the distribution of dwarfmistletoes and the severity of infection they cause. Plot and roadside surveys revealed widespread, severe infection in Douglas-fir and western larch stands on the Colville National Forest and adjacent private lands in northeastern Washington. Infection in ponderosa pine stands was limited mostly to the southern part of the surveyed area. Many of the lodgepole pine stands, especially in the northern part, were infected. Infection in other species was infrequently encountered. It is obvious that control of dwarfmistletoes is needed, e.g., that a high percentage of the merchantable volume in larch and Douglas-fir is in infected trees and that a positive correlation exists between tree mortality and dwarfmistletoe infection.

The western spruce dwarfmistletoe, Arceuthobium campylopodum f. microcarpum, is known only from Arizona and New Mexico where it is very damaging to Picea engelmannii and P. pungens. Other dwarfmistletoes (A. americanum, A. campylopodum f. laricis, A. campylopodum f. tsugensis, A. douglassii, and possibly A. campylopodum f. cyanocarpum) may sometimes attack western spruces. These have been the basis for reports of A. campylopodum f. microcarpum occurring elsewhere in the West.

The dwarfmistletoe that attacks Chihuahua pine in Arizona and northern Mexico is a new species and not Arceuthobium vaginatum as previously thought. It differs from A. vaginatum not only in the hosts attacked, but also morphologically and phenologically. A formal description of this new species is in preparation.

Three years of research on the epiphytology of Arceuthobium campylopodum on true firs in California show that the dwarfmistletoe seeds produced on white fir infect only white fir and those from red fir infect only red fir. The minimum time for dwarfmistletoe to complete its life cycle on red fir is about 4 years. Symptoms of infection may appear 2, 3, and 4 years after seed dispersal.

Seedlings of coastal Douglas-fir and seedlings taken from Douglas-fir stands in central Montana became infected when inoculated with dwarfmistletoe in the greenhouse. Dwarfmistletoe does not naturally occur in the coastal form Douglas-fir on the west side of the Cascade Mountains in Washington and Oregon north of the Siskiyou Mountains of southern Oregon, or in Douglas-fir stands of central Montana.

Results of inoculations at Pullman, Washington, reveal that susceptibility, host symptoms, and development of the parasite are no different in these seedlings than in seedlings of the intermountain form of Douglas-fir.

High-speed photographs of the ejection of Arceuthobium seed from its fruit show that tumbling in the vertical plane begins soon after discharge and that most seeds have turned by a quarter of a circle when they have traveled about 5 cm. As the seeds leave the fruit, they have a viscous sheath around the trailing end that disintegrates after the seeds have traveled about 2 to 3 cm. The viscous material does not act as a rudder as has been postulated.

Dwarfmistletoe attack and damage on Abies magnifica is more extensive than for any other host conifer in California. Microscopic examination of sections of red fir tissue at 1-month intervals from June through September during the time "hold fast" or attachment tissue is being formed showed the hold fast produced wedge-shaped tissue which penetrated host cells by mechanical action.

In an Intermountain study, seed of A. americanum, A. campylopodum f. campylopodum, A. c. f. abietinum, A. c. f. laricis, and A. douglasii were stored dry at 50° C. for about 150 days and then immersed in 1-5% H_2O_2 . Germination was obvious after 4 days in hydrogen peroxide solution. After 10 days, radicles averaging 0.34-0.69 mm. had developed, the length increasing with increasing concentrations. Percentage viability was lower when determined by this method than by the triphenyl-tetrazolium chloride test. The H_2O_2 test, however, is more reliable and more useful than staining tests for viability since it results in direct germination of the seed.

An understanding of the longevity and germination of dwarfmistletoe seeds is basic to problems of spread and intensification of the pest in coniferous timber stands. Studies in California show that dwarfmistletoe seeds do not require a period of after-ripening but favorable temperatures are required. Light, though not essential, stimulates and increases germination.

In an inoculation study in Idaho a high percentage of the dwarfmistletoe seed placed on the coniferous seedlings were removed by melting snow in the spring. Of the seed remaining on the seedlings many were not well attached and were subsequently removed during the spring rains (April-June). All seed had been strategically placed on the seedlings for best retention and should have had a far better chance of remaining on the seedlings than would naturally expelled seed. The results offer one valid explanation of why seedlings under 8 years old are rarely found infected in nature. Height, correlated with depth of snow cover, rather than age per se, determines when initial persisting infections occur.

In studying possible agents for biological control of dwarfmistletoes, Septogloeum gillii was found to be prevalent on A. campylopodum f. campylopodum, A. c. f. abietinum, A. c. f. laricis, and A. c. f. tsugensis during 1961 in the vicinity of White Pass, Cascade Mountains, Washington. The fungus also was found on A. c. f. campylopodum about 12 miles south of Spokane, Washington. An apparently undescribed species of Pestalotia also was found on plants of A. c. f. abietinum in the White Pass area. This constitutes a new host record for the genus Pestalotia. An unidentified imperfect fungus attacks plants of the 4 forms of A. campylopodum listed as hosts for S. gillii at White Pass. This fungus has been found only on dead plants, but field observations indicate that the fungus

killed the plants. Wallrothiella arceuthobii is prevalent on A. americanum in the Sherman Creek drainage, Ferry County, in northeastern Washington. Mature asco-spores were collected in early April, 1962. The fungus occurs sporadically on A. douglasii in the Moscow Mountains near Viola, Idaho.

Chemical control of dwarfmistletoes in California was secured by direct application of spray to the parasites. The greatest selectivity between hard pine hosts and parasites and best combination of direct and systemic action was achieved with the 2,4,5-trichloropropionic, the 2,4,5-trichlorobutyric and the 4-chlorophenoxyacetic weed killers. The most practical on the combined score of cost, availability, and effectiveness in direct treatment is the 2,4,5-trichloropropionic formulation.

f. Heart rots. Commercial thinnings in young stands cause many wounds on residual trees and thereby increase the number of infections by wood-destroying fungi. Studies in the Pacific Northwest showed that western hemlock was more subject to wounding and subsequent decay than was Douglas-fir. Large wounds and wounds near the ground were more frequently infected than were small wounds on the upper parts of the trunks. As young stands are brought under intensive management, care must be taken to protect residual hemlocks from injuries, especially skidding wounds.

Wounds on residual trees caused by logging are also an important means of entry for decay fungi and other tree pathogens in the northern hardwoods type, and activities of such organisms cause great losses. In a long-term study, an early evaluation indicates that losses are appreciable as early as 4 years after wounding, that root wounds may be more damaging than stem wounds, and that wounds on yellow birch often increase in size through margin dieback. Such information is useful to forest managers in evaluating logging damage and identifying high-risk trees for early removal.

Ring shake in northeastern hardwoods and softwoods was correlated with injuries made by the yellow-bellied sapsucker. The old wounds may be good external indications of internal defects.

Echinodontium tinctorium is a major cause of heart rot in several Intermountain conifers. Little has been done in defining its life cycle, and previous attempts to collect and germinate its basidiospores have not been successful. Viability and germination of the basidiospores and growth of the germ tube in different solutions are being studied. Evidence indicates that the basidiospores are nutritionally independent but have rather stringent moisture requirements and may even require an aqueous medium for germination. Inoculations of grand fir with E. tinctorium appeared successful at the end of the first growing season.

4. Foliage Diseases

a. Elytroderma needle blight. Except for infection studies, laboratory investigations on the life cycle of Elytroderma deformans have been completed at Montana State University. Cytological studies of many physiologically different isolates of the fungus showed that a changing nuclear condition (from multinucleate to binucleate to uninucleate) in the systemic and the sporocarpic-producing hyphae occurs in both cultures and living material. This nuclear condition is the key to revealing the major part of the life cycle of the fungus.

In another study at M.S.U., tritiated uridine was incorporated into the cytoplasm of vegetative hyphae and of the plectenchyma layer of Elytroderma deformans hysterothecia growing within the needles of ponderosa pine. This material readily entered hyphae in the resin canals, mesophyll, phloem, xylem and transfusion cells of the pine needle. Attempts to introduce tritiated thymidine in a similar fashion gave inconclusive results. The utilization of H^3 uridine should provide new information on the location of hyphae within host tissue and help elucidate host parasite relationships.

b. Brown spot of longleaf pine. Brown spot, caused by Scirrhia acicola, is one of the limiting factors in the successful regeneration of longleaf pine. A possible partial explanation for field variations in disease intensity and control efficacy was found in a nutritional study of the pathogen, carried out at Gulfport, Mississippi. Among six isolates of Scirrhia acicola there were strains differing in nutritional requirements, growth rate, and spore-producing ability. Three isolates required no additional vitamins for growth or sporulation; two required thiamine; and one biotin. Usually growth was increased by adding carbohydrates or phosphates to the medium. Maximum growth occurred in 21 days at pH 5.8-6.0; spores germinated best at 25° C.; and the thermal death point was about 40° C. These results form a sound basis for devising technics for mass producing spores for inoculation trials in genetic studies of brown spot resistance.

c. Emergence tipburn of eastern white pine. Because of similarities of the emergence tipburn disease of eastern white pine with air pollution damage, studies of the etiology of emergence tipburn are under way to determine the relationship of this disease to air pollution damage to white pine. Attacks of emergence tipburn during the summer of 1961 in West Virginia occurred during a period of high atmospheric oxidant concentration. In this period, oxidant concentrations as high as 6.5 p.p.h.m. were recorded. Potted susceptible white pine ramets were protected from emergence tipburn by placing them in a chamber supplied with air filtered through activated carbon. Typical disease symptoms were produced on ramets in the greenhouse, using artificially produced ozone at concentrations and exposure times similar to those recorded in the field, thus strengthening the thesis that ozone is a cause of emergence tipburn.

In order to learn more about the symptoms of each type of injury, clones of both emergence tipburn (ET) susceptible and resistant pines were exposed to air pollution conditions in east Tennessee. These clones were compared to clones both resistant and susceptible to air pollution injury -- post-emergence chronic tipburn (PECT). The response of the ET-susceptible clone was similar to its response to ozone, except that when exposed to air pollution in Tennessee the reaction was much more severe. Since the times of tipburn occurrence are different, it is believed that the ET-susceptible clone and the PECT-susceptible clones may be responding to different constituents in the atmosphere. Thus we have good leads for our research on qualitative air pollution indicators.

d. Post-emergence tipburn of eastern white pine. Since root and stem aphids had been found in association with post-emergence chronic tipburn in Tennessee, a study was begun in 1959 to determine whether recovery of diseased trees could be induced by use of insecticidal sprays and drenches. Aldrin, benzene hexachloride (BHC), and malathion were used for foliar treatments, and Aldrin, BHC, and DDT were used as soil treatments. A number of diseased check trees received no

treatment. The Dowfume treatment was lethal, but the other treatments eliminated insects from the foliage or roots. Observations during the 3-year period, April 1959 to May 1962, failed to reveal any improvement in the disease condition of any of the trees used in this study. This indicates that insects infesting the foliage and roots of white pines are not involved in causing post-emergence chronic tipburn in eastern Tennessee.

e. Chlorotic dwarf of eastern white pine. Previous studies in Ohio have essentially eliminated malnutrition, needle fungi, virus, and soil moisture stress from among the possible causes of this disease. Two other leads are now being followed:

Prior to 1962 bud break, chlorotic dwarf pines in a Blue Rock (Ohio) plantation were enclosed in 25 cu. ft. chambers for the purpose of removing pollutants from air reaching the trees. Chambers were either completely covered with plastic or else equipped with two 12- by 18-inch filters composed of 3-inch-thick Fiberglas or specially treated charcoal. None of the trees showed chlorotic dwarf symptoms. Uncovered pines exhibited typical disease symptoms. These results suggest an association with air pollutants.

To determine whether or not there is genetic variation in susceptibility or resistance to this disease, 2-0 seedlings of known female parentage were outplanted in the spring of 1962. Approximately 3400 seedlings were planted at each of two locations in Blue Rock and Mohican State Forests (Ohio), respectively. Counts made during the fall showed 77 percent survival for Blue Rock and 43 percent for Mohican. The future development of chlorotic dwarf in these seedlings will be recorded.

f. Chlorotic decline of ponderosa pine. A chlorotic decline, first noted in the early 1950's, has affected ponderosa pine over several thousand acres in the San Bernardino Range in California. Examination of and isolation from roots, stems, and needles failed to disclose any consistent association with pathogenic organisms. Drought, air pollution, or a combination of the two are suggested as possible causes.

g. Miscellaneous foliage diseases. A previously undescribed witches' broom is widespread on Gambel oak in Colorado, Utah, Arizona, and New Mexico. An imperfect fungus (Articularia quercina var. minor Charles) is consistently associated with the brooms and is probably the causal agent.

Cross-inoculation studies at the Raleigh, N. C., laboratory with isolates of Cercospora magnoliae from Magnolia grandiflora and M. virginiana produced leaf spot symptoms typical for the respective host regardless of the source of inoculum. Although the symptoms of the disease on the two species are different, and the conidiophores of the fungus are twice as long on M. grandiflora as on M. virginiana, the cross-inoculation studies show the leaf spots to be caused by the same organism.

During examination at Raleigh, N. C., of numerous fresh and herbarium specimens of fungi occurring on eastern redcedar and related conifers to determine the identity of a fungus causing a serious needle blight of redcedar, four distinct, although morphologically similar, fungi were encountered which were being confused with one another. The causal agent of the needle blight fungus on redcedar was found to be Cercospora sequoiae var. juniperi. The taxonomy, host range, and distribution of this fungus as well as Cercospora sequoiae, Stigmata juniperina, and S. glomerulosa have been clarified.

In a study of diseases of native firs and pines and of Pinus radiata in Spain, 142 pathogens have been collected and identified, including two of potential importance to the U. S. One is a new and virulent needle cast of hard pines and the other a possibly distinct race of the fungus that causes brown spot needle disease of our southern pines. (PL-480)

Seeds of all potential North American hosts have been sent (8 pines and 5 poplars) and seedlings are now established for a study in Italy to determine their relative susceptibility to Melampsora pinitorqua, the cause of pine twist rust. (PL-480)

5. Systemic Diseases

a. Oak wilt. Two methyl bromide fumigation tests with oak wilt infected black oak logs were completed by the Central States Station, (1) logs cut and treated at peak symptom expression and (2) logs cut and treated 3 months after peak symptom expression. The oak wilt fungus could not be recovered from fumigated logs in either test but was recovered from all check logs in both tests. This is another step forward in developing a technique of sanitizing infected logs so that they may be acceptable for export to countries now having embargoes.

Ethylene was not detected as a product of in vitro cultures of the oak wilt pathogen, Ceratocystis fagacearum. Ethylacetate, a metabolite of C. fagacearum, was found to be toxic to young red and white oak trees. In vitro culture filtrate (sterile filtered) taken up by oak cuttings produced foliar symptoms similar to those of the oak wilt disease. No wilt symptoms were observed in a variety of herbaceous plants inoculated with the oak wilt pathogen. A pressure system was devised to force fluid from the xylem of tree sections. Preliminary chromatographic studies do not show consistent differences in individual amino acids and phenols from oak wilt infected and check oak tree xylem fluid.

In an experiment to determine the importance of the small oak bark beetle in the spread of the oak wilt disease in Missouri, beetles were reared from naturally infected trees and the presence of viable spores of the fungus on such insects was determined by the spermatization technique. A high percentage of the diseased trees yielded contaminated beetles and a good percentage of beetles from individual trees were contaminated.

The oak wilt fungus sometimes spreads for short distances through natural root grafts between diseased and healthy trees. In another study it was shown, however, that root grafts are not as common as formerly supposed, indicating that short distance spread may occur in other ways. One possibility is that the fungus is able to move from diseased roots for short distances through the soil to adjacent healthy roots and enter these roots through insect or other wounds. Recent soil and root inoculations in Missouri indicate, however, that the oak wilt fungus is not free-living in the soil although it can be transmitted through root inoculation.

b. Pole blight of western white pine. Five seedlings each of Douglas-fir, grand fir, western larch, western redcedar, and western white pine were grown together on three different soil types at Priest River, Idaho. After a two-year establishment period, seedlings growing in paired bins of each soil type were subjected to two moisture stress treatments for three growing seasons. The study was replicated, providing 10 plants per species for each of the 6 treatments. Both

within and between species differences in responses were observed. Analysis of the results will provide a better understanding of the pole blight disease of white pine.

c. Hardwood diebacks. Progress of dieback has been analyzed in northern hardwood stands in which over 2,000 trees have been evaluated on an individual basis annually since 1958. Dieback increased each year with damage greatest in heavily cut and less in moderately cut stands. Larger trees (15+ inches d.b.h.) are most severely affected, with about 50 percent showing symptoms, while only 7 percent of the pole-size trees (5 to 9 inches d.b.h.) were affected. Nearly all affected trees have less than one-half the crown involved, and fewer than 1 percent have died since 1958. Unfavorable climatic conditions have been postulated as a possible cause of dieback. Such information will be useful in correlating dieback with weather records and enable a better prediction of the course of dieback in affected stands.

Maple dieback is widespread in the northern hardwood type in the Lake States. As part of the investigations aimed at discovering the cause of the disease, it was necessary to make basic studies of the anatomy of sugar maple rootlets and their associated fungi to distinguish between normal and abnormal root systems. Prior to this work the anatomy of sugar maple rootlets containing mycorrhizal fungi was unknown. This work provides that information and is a contribution to basic knowledge of use in plant anatomy, plant physiology, and plant pathology.

Unfavorable climatic conditions have been postulated as a cause of maple dieback. The results of greenhouse studies with potted sugar maple seedlings show that if water tables remain high just as the buds are bursting in the spring, rootlet mortality and foliar wilting can occur. These results are the first solid lead on the cause of maple dieback and furnish the basis for more elaborate field studies planned for large trees during coming field seasons.

Sapstreak disease of sugar maple was first discovered in the Lake States region in 1960. During 1962 several new cases were found. The disease does not appear widespread at present, but may be potentially dangerous. In one stand closely examined following logging, nearly 10 percent of the trees cut were infected. Strong circumstantial evidence indicates that the causal fungus enters through wounds on healthy trees.

Extensive deterioration of American plum in Plains windbreaks probably is not due to necrotic ring spot virus. Typical symptom development in index plants indicated that the virus was present in less than 0.5 percent of the sampled trees.

6. Decays of Wood and Wood Products

a. Decays of killed timber. Eleven-year-dead standing beetle-killed Douglas-fir trees dissected in 1962 at eight locations in western Oregon and Washington showed a decay volume loss of 79 percent on a board-foot basis, and 70 percent on a cubic-foot basis. None but the largest trees (36 inches d.b.h. and larger) had any significant salvable volume. Practically all of the remaining salvable volume is in the first 16-foot log.

b. Decay of raw products. Studies in the Northeast showed that Ceratocystis coerulea was usually the first fungus to infect ends of hardwood bolts cut

for pulpwood. The expanding mycelial patches were commonly overgrown by Cephalosporium sp., Gliocladium roseum, and Trichothecium roseum which were responsible for changing the color of the ends from black to white.

A laboratory method was devised at Madison for testing the decaying ability of specific soft-rot fungi under conditions simulating those in the outer zone of chip piles. Twenty-six organisms were tried on sweetgum wood; highest average reductions in specific gravity were 42 percent by a Basidiomycete and 18 percent by a soft rotter. All soft-rot isolates that were tested were identified to genus. The Basidiomycetes could not be identified, hence may not be common decay organisms.

The number of genera verified in the laboratory as soft-rot fungi was increased to approximately 50. Genera isolated from soft-rotted wood and at least tentatively named, total more than 100. Considerable evidence was found that soft rotting of coniferous woods, which generally has been relatively very slow, may be promoted by increasing the carbon dioxide content of the atmosphere.

Selective trials were made from which four soft-rot fungi were chosen as being suitable test organisms for use in development of a standard test of preservative effectiveness. Evidence was obtained that another factor of the culture environment -- possibly increased carbon dioxide -- must be regulated if a soft-rot test is to have validity comparable to that of the standard soil-block test for preservatives.

In a study to distinguish between chemical and oxidation stains in sapwood, observations of 12 different hardwoods indicated that a general characteristic of chemical stain may be the development of brown-colored deposits in the rays and other parenchymatous cells, accompanied by progressive disappearance of starch granules. The discoloration in all cases was markedly reduced but not eliminated by oxalic acid. The depth of color in the brown deposits was not reduced, however, which suggests that the discoloration does not reside entirely in these deposits. Variable effects on stain development were obtained by preheating the wood, cold storage, or rapid drying. Limited confirmation of oxygen as an essential factor was provided by the absence of staining of sugar maple in an oxygen-free atmosphere.

In another study at Madison, it was established that some bacteria in a period of six months can cause reductions in wood weight of between 5 and 10 percent, with accompanying large increases in permeability and losses in strength of the infected wood. Such effects were about half as great in six weeks. The number of isolates identified to species was increased to 10. Most are Bacillus species (common aerobic spore former), but two unexpected genera were found.

c. Decay of wood in use. The last of a series of laboratory appraisals under Navy contract, of dip, spray, brush, and spread treating of exterior woodwork was terminated at the Forest Products Laboratory. Brush or spray treatment with high concentrations of preservative did not appear in laboratory bioassays to be as effective as dip treatment with conventional concentrations. A final segment of the field phase of the study was installed with assistance from the Southern Station. Trials of spray treating of structures in place, at three naval activities, showed little promise for the method if applied to older structures; apparently the preservative solution does not readily penetrate to the deeper zones of incipient decay.

Studies conducted at the Southern Station lead to the same conclusion that on-the-job applications of preservatives, in general, give marginal protection against decay unless carefully used. Additional information was secured on the effectiveness not only of pentachlorophenol but also phenyl mercuric oleate, copper naphthenate, copper 8-quinolinolate, and copper 3-phenyl salicylate when applied as 3-minute dips to southern pine sapwood. Water repellents increase the effectiveness of most toxicants used as wood preservatives. Doubling the usual concentrations of solutions of sodium pentachlorophenate and pentachlorophenol did not materially increase their effectiveness when applied as 3-minute dips. Quadruple concentrations increased effectiveness but it is doubtful that the increase is sufficient to offset the high cost of such concentrations. Copper naphthenate 2 or 4 percent Cu, applied as 3-minute dips in ammoniacal water solutions gave approximately the same protection as in oil solutions. The water solution was definitely inferior at 1 percent Cu.

Extensive past tests demonstrated that dips and short-period soaks of pre-cut lumber in solutions of pentachlorophenol or copper naphthenate greatly extended the service life of southern pine exposed in south Mississippi. The studies here reported extended this work to other wood species with exposures in Mississippi, Wisconsin, and Oregon. Results indicate that a 3-minute dip can effectively protect exterior woodwork of a variety of softwood species against decay for 7 or more years in a variety of climates. The woods included were: Douglas-fir (mill run and sapwood), ponderosa pine (heartwood and sapwood), southern pine sapwood, western hemlock (mill run), and white fir (mill run). Except for the small to moderate amount of decay in treated sapwoods of ponderosa and southern pine, both porch flooring and step-rail units of all species are essentially sound after 7 years' exposure. The relative decay rate of the untreated units of the four most decay-susceptible species were: rail units, Wisconsin 0, Oregon 1, Mississippi 3; and for flooring 1-2-5, respectively.

d. Natural durability. All samples have been collected and most of the laboratory testing completed in a study at Madison to evaluate the natural decay resistance of old-growth and young-growth redwood. Little difference in resistance was seen between old-growth and second-growth material. Surprisingly, both exhibited a general level of resistance below that indicated by the reputation of the species for durability. Stakes of old-growth wood were set on the Harrison and Madison exposure sites. In another study, it was determined that the fungicidal components of both black locust and osage orange are largely soluble in hot water, although some additional extracts can be removed with methanol and benzene-alcohol followed by hot water. The toxicity of the extracts appeared to be reduced by the extraction process.

The relative durability of Indian woods of commercial importance in international trade is being determined at the Forest Research Institute, Dehra Dun, using the soil-block technique perfected at the Forest Products Laboratory. For comparative purposes, samples of redwood and black locust, and certain test fungi were sent to the Institute from the U.S.A. for inclusion in the study. (PL-480)

e. Fungicidal properties of wood preservatives. Bioassays run at the Forest Products Laboratory indicated that Trichoderma, a common soil and wood mold, destroys pentachlorophenol-petroleum preservative. Similar destruction of arsenic-chromate-fluoride preservative previously reported was shown by chemical analyses to entail a large loss of arsenic. Judging from analogous observations by others, the arsenate or arsenite was converted to trimethyl arsene, a gas.

f. Cultural identification of fungi. In the service-research program of the Laurel Laboratory 885 pure cultures of fungi causing decay in trees and woods products were received for identification, and determinations of 975 isolates were reported. Some of the isolates determined were received several years ago and classification patterns were only recently obtained to permit identification. The reference collections were increased by 336 cultures including 8 new species and 392 new haploid isolates representing 42 species. Twelve additional species were studied. Notebook descriptions and identification cards were made. Eight species were restudied. Notebook descriptions and identification cards were revised. A total of 763 haploid pairings in 92 isolates from 21 species were made.

Preliminary trials at the Forest Products Laboratory with different genera of Basidiomycetes indicated that generic separations possibly could be made by chromatographically observing differences in the metabolically produced acids. A satisfactory method of separating known organic acids by paper chromatography was found. Within a single genus, Poria, chromatographic distinctions between species were less promising. However, a combination of chromatography and variable growth characteristics of the different species in liquid culture offers promise.

Radial growth of fungus clones in pure culture at various temperatures is being used at the Laurel Laboratory in an attempt to provide an additional tool for distinguishing between otherwise similar clones or species. In another procedure, dry weight of the fungus mat developed in liquid culture media is being used as a measure of growth.

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IV. FOREST PRODUCTS AND ENGINEERING RESEARCH

A. FOREST PRODUCTS UTILIZATION RESEARCH

Problem

The timber-using industry is an important part of our present economy. In 1959 the total value of shipments from timber-based primary manufacturing industries amounted to over \$10 billion. About 5 percent of the Gross National Product originated in timber-based industries. One out of every 20 people employed in the United States worked in these industries. A raw material base for a greatly expanded industry is available in little-used species, in low-value timber, and in logging and milling residues. Research in forest products utilization is needed not only to give stability to the present industry but also to develop a technical basis for new industries.

The Federal Government has a strong interest and responsibility in forest products utilization research. The timber industry does a substantial amount of research. However, the industry is a complex of many small companies. Even the largest are small in comparison to those of other basic industries with whom they compete, i.e., aluminum, steel, plastics, and petroleum. One single large petroleum-using company employs more researchers than the entire timber-using industry. There are very few forest products companies who can finance a research program. Those that do are largely interested in developments which will give them a competitive advantage. Basic research by industry is largely neglected.

The problems are especially acute on the considerable acreage of timber in small ownerships. Here the continued "creaming off" of the better timber has resulted in residual stands of low value under present use standards. Research is needed to develop uses for this presently unmarketable timber.

The Federal Government itself owns and markets over a hundred million dollars worth of timber each year. The value of this timber can be greatly enhanced by the development of more profitable uses. Also proper forest management will be facilitated by developing markets for thinnings and other low-value timber.

The strength of the United States in times of emergency will also be improved by the development of industrial chemicals from wood. This will relieve petroleum which has been a critical raw material in times of war.

Program

The Department has a continuing long-term program involving both basic studies and applied research on problems relating to forest products utilization. Because its broad objective is to promote better utilization of the nation's timber resource, the required research and development draws upon the skills of many scientists in widely divergent fields. Involved are some 20 scientific disciplines in the areas of chemistry, engineering, mathematics, physics, and biology.

Basic studies are carried on in many subject areas to provide a solid background of fundamental information on the nature and properties of wood and its components and on the factors that affect those properties. Such research includes studies of strength, physical properties, chemical composition and reactions, anatomical structure, and resistance to decay, insects, fire and other destructive agencies.

Based on adequate background research findings, developmental work to improve the usefulness and the competitive position of wood and wood products proceeds in many ways. For example, improved preservative treatments may greatly lengthen useful life; improved glues and gluing techniques will improve the performance of glued products; and the development of precise design criteria for lumber, plywood, laminated wood, and fastenings for them will improve the performance of structures and, at the same time, reduce their cost.

Research that develops better standards of quality and value in trees and logs, better saws and more efficient sawing techniques, and other processes will be effective in extending the timber supply. At the same time, research that improves decay resistance reduces replacement requirements, and more efficient research-based design can reduce the amount of wood needed in structural units.

Drain on timber supplies of high quality and preferred species can be further reduced by research that results in expanding the use of cull trees, little-used species, small and crooked trees, and residues in the woods and in the mills, especially as related to chemical conversion and expanded development of glued and pulp products. The pulp industries, for example, depended for many years on a limited group of softwood species. As demand grew, technologic development brought about the use of additional softwoods and, more recently, a wide variety of hardwoods.

The key role that wood utilization research plays in the area of wood quality has been increasingly recognized in recent years by foresters, timber owners, lumbermen, plywood producers, and makers of wood fiber products. Rate of growth, density, fibril angle, and other basic indicators of wood quality are all governed to a great extent by growth conditions in the forests, and these conditions are in turn proving manageable to an extent that heavily influences the quality of the wood produced.

Research is underway to evaluate the intrinsic wood quality of standing timber; establish what effects such environmental factors as soil and rainfall, and such silvicultural treatments as pruning, have on quality; investigate by microscopic and other means how the physical structure of wood is related to its properties; and assist in the establishment of quality grades for trees and logs.

The processes and treatments by which wood is made serviceable, from the sawing of round logs to the utilization of sawdust and other processing residues, come within the scope of research on solid wood products. Included are the many kinds of operations involved in the processing and protection of wood in its solid form. The production of lumber, veneer, plywood, laminated wood, and particle board; product and process development; machining operations; preservative and fire-retardant treatments; painting and finishing; glues and gluing techniques; and seasoning operations comprise the principal processing investigations under study.

Supplementing these are basic studies that encompass fundamental cutting actions of saws, knives, and other tools; chemistry of preservatives, fire retardants, adhesives, and finishes; pyrolysis and related effects of heat and combustion; environmental effects; and the growth and life cycles of decay and staining fungi, bacteria, and insects that attack wood.

Year by year, more and more wood is transformed into substances whose origin in trees is unrecognizable. Wood is our main source of fiber for myriad pulp and paper products, the demand for which continues to mount. By 1975, it is expected that 40 percent of all wood used will go into these products. As a result, greater pressure is put on our timber supplies and research is called on to broaden this raw material base.

An intensive program in the field of wood fiber products is carried out on pulping processes and pulp properties; on wood fiber properties related to pulp and paper production, and on the manufacture and properties of paper products. The object is to make hitherto unused species and qualities suitable and to produce more pulp from less wood.

Production of chemicals from wood is at a much younger state of development, necessitating primary emphasis of fundamental research and process development in the field of wood chemistry research. Basic studies are undertaken on the chemistry of wood carbohydrates, on the structure and chemical behavior of lignin and the extractions of wood and bark, on the biochemistry of wood constituents and their microbiological conversions, and on the surface and polymer chemistry of wood. These are carried on not only to provide basic knowledge essential to the development of broader industrial chemical conversion of wood, but also to provide a basis for determining fundamental relations between chemical and other wood properties such as strength and factors affecting strength, treatment, seasoning, dimensional stabilization, finishes, and the like.

Wood engineering research deals with the establishment of the mechanical, physical, and related properties of the many species of wood commercially used, and the effects of use conditions on these properties. The same properties and conditions are investigated as they apply to plywood, laminated wood, chemically treated wood, fiberboard, particle board, paper and paperboard products, and composites of wood and other materials. Increasingly important is research on the use of wood in housing, farm structures, and other light-frame buildings. Included are studies on development of mathematical and theoretical concepts for the behavior of wood and wood-base materials under stress and the establishment of design and performance criteria for more effective use of wood and wood-base materials as structural components, including the broad field of packaging.

A vital adjunct to the production of research information is its dissemination and application in practice. Although this can be done in part through the medium of publication, far better results are obtained by on-the-ground consultation and interpretation of research findings to specific problems. This is a prime responsibility of the forest utilization research scientists at the Regional Experiment Stations. Furthermore, their frequent contacts and intimate knowledge of the regional wood-using industries permit them to determine significant problems in need of solution, and thus provide a basis for integrating them into a national research program.

Similarly, the experience and knowledge of scientists at the Forest Products Laboratory and at the Regional Experiment Stations has proven invaluable in connection with technical reviews of proposals submitted for consideration under the Rural Areas Development efforts of the Department of Agriculture, often in connection with proposals for industrial developments submitted to the Area Redevelopment Agency of the Department of Commerce.

Research is done mainly at the Forest Products Laboratory at Madison, Wisconsin, and at the Regional Forest Experiment Stations and the Institute of Tropical Forestry. Where suitable, however, cooperation is arranged with universities, other Federal or State Government agencies, private laboratories, professional societies, industry associations, or with industrial companies. Likewise, cooperative research may be done for industries or private individuals where its accomplishment ties in and will benefit the planned research program. During the past year cooperation has been with 16 colleges and universities, 21 Federal and State Government agencies, 34 industry associations, several private laboratories or professional societies, and more than 100 private companies.

The Federal scientific effort devoted to research in this area now totals about 166 professional man-years. Of this number, 45 are devoted to regional utilization problems at the Forest Experiment Stations and the Institute of Tropical Forestry, and 121 are at the Forest Products Laboratory. Of the latter, 25 are in the field of wood quality, 37 in solid wood products, 9 in wood fiber research, 27 in wood chemistry, and 23 in wood engineering research.

Research in this field is also performed by State laboratories such as those in Oregon, California, and Texas and by numerous schools. Substantial research is now going forward in industry-supported laboratories and those of individual companies. It is estimated that the total industrial research effort in this field involves the equivalent of about 2,000 scientific man-years; and that performed by public agencies outside the Federal Government about 100 man-years. Industry research is, of course, performed largely to obtain competitive advantage and is generally not freely available.

Within the past several years, a program of research in foreign countries has developed under Public Law 480. Many projects have been proposed in the field of forest products in 20 different countries. Currently five projects are underway involving about 10 professional man-years per year. One project in Peru involves collection of authentic herbarium samples and wood from Peruvian trees. Four Finnish projects are on factors affecting impregnability of wood, aerobic bacterial degradation of lignin, accessibility studies of cellulose fibers, and moisture-temperature-time relations as they affect wood strength properties. One project, located in India, is approved and work is to begin shortly. It will involve 6 professional man-years per year on the subject of working qualities of Indian timbers.

Progress

1. Wood Quality

An overall problem analysis of timber quality research needs, mentioned in last year's report as initiated, is scheduled for completion this year. This analysis will provide an improved guide both to the Forest Service and to other research agencies in selecting for study specific segments of the wood quality problem.

a. Fine wood structure. Following last year's initial observations on the presence of lignin in the outer layers of spruce fibers, current studies of pine and spruce confirmed dense and compact lignin concentrations in the intercellular and adjacent primary wall layers and in the inner layer of the secondary wall. In the outer layer of the secondary wall, lesser concentrations of laterally oriented lignin were found, diminishing toward a dispersed network in the central layers. Lignin in sugar maple was also highly concentrated in the inner and outer layers of the fibers but generally was less concentrated in the central layer.

Electron micrographs of white rots showed invasion of the fungi into the fiber walls as well as degradation along the lumen, in contrast to more complete wall deterioration caused by the brown rots.

b. Wood structure-wood property relations. A study of the relationship between wood structure and strength properties of loblolly pine showed that specific gravity accounted for surprisingly small amounts of the total variances of both maximum strength and stiffness in end crushing, while fibril angles accounted for appreciably more of the total variances. The combined effects of specific gravity and fibril angles accounted for 85 to 90 percent of the total variances. The separate effects of these features on the strength properties of white ash were determined. The analysis showed that specific gravity accounted for 62, 47, and 32 percent of the total variance, respectively, of modulus of rupture, end-crushing, and modulus of elasticity, while the combined effects of specific gravity and fibril angles in the summerwood accounted for 81, 54, and 59 percent of the total variances.

An early study of the effect of nitrogen fertilization of red oak, white ash, and yellow-poplar trees showed that maximum growth response--as much as 400 percent--occurred within 3 years after the treatment. Effects of nitrogen fertilization have now been found to continue much longer than indicated in the original study. While large increases in diameter growth sometimes cause serious surface roughening of molded edges and turnings, evaluations of machining quality of the wood from fertilized trees showed only a few minor defects associated with localized grain deviations, and only slight surface roughness.

c. Environmental, growth and silvicultural effects. A tree trunk can be graphically represented by a series of cones nested one in another, each representing a layer of annual growth. The method affords a realistic picture of overall stem growth, indicating for each cone, or increment sheath, the areas along the length of the stem where annual accretion of summerwood and springwood is greatest or least. This in turn can be related to weather records, site quality, and other variables.

Studies of loblolly pine have shown that within each increment sheath there exists a systematic variation in wood structure from its apex to its base. Also, soil water deficiencies occurring commonly in the South are responsible for fantastic losses in volume growth in young loblolly pine stands. Previously no quantitative information was available concerning the losses in terms of wood quality. Analyses demonstrated a highly significant correlation between water deficits and many anatomical features. For instance, when there was virtually no water deficit, summerwood percentage values that were low in the crown increased very rapidly towards the base of the trunk whereas at the other extreme, under severe drought, summerwood percentage values that were high near the apex actually decreased towards the base. The main difference between the two sites studied was in the moisture-holding capacity of the soil that effects both height and diameter growth. For the poorer site, springwood growth was reduced more than summerwood to give a slightly higher percentage of summerwood in the increment sheaths resulting in a generally higher specific gravity for the poorer site (around 6 percent); however, the tremendous reduction in volume (60 percent) more than offsets the slight increase in specific gravity.

This study is expected to demonstrate limitations within which timber management practices can be applied to loblolly pine to attain higher quality wood through more uniform tree growth.

d. Wood quality evaluation and genetic effects. The large industry-supported increment core sampling of 30,000 trees of 25 species from 11 Western States was completed this year along with specific gravity, age, and sapwood measurements. Related data obtained from 1,400 felled and dissected trees of the 9 highest priority species showed that in 7 species the relationship of core specific gravity to that of the whole tree did not vary significantly with geographic location. Two exceptions were Douglas-fir and white fir from Arizona. Prediction equations were developed using tree diameter and breast height increment core specific gravity to estimate average tree specific gravity. Analyses are being continued with the aid of an electronic computer to determine the effects of stem diameter, age, volume, and other characteristics on specific gravity.

The 10-inch-long increment cores obtained from the western species, often from large trees representing only a partial radius, show closer correlations with whole-tree gravity obtained from disks than was the case with full-radius cores taken from the southern pines. This is due to the fact that although wood near the pith of trees varies considerably in density from that grown later in the tree's life, the later wood constitutes the bulk of the tree's trunk; a full-radius increment core, therefore, gives disproportionate importance to the comparatively small amount of juvenile wood.

Mass sampling and processing of southern pine increment cores from Georgia, Florida, Arkansas, and Alabama revealed a trend toward an increasing specific gravity of wood from northwest to southeast through both Georgia and Florida. The pattern is quite similar to that originally found in Mississippi, except that latitude appears to have a greater effect on slash and longleaf pine, especially in Florida, probably due to local climate and soil conditions. Slash pine ranged in average specific gravity from 0.42 in central Georgia to 0.66 in southern Florida. Loblolly pine's variation was not so great, from 0.46 in the north to 0.56 in the south of this range, and longleaf pine varied least, from 0.52 to 0.60. One of the major markets for southern pine in this area is for pulpwood, so specific gravity has a practical significance. A difference of only 0.02 in specific gravity is equivalent to 100 pounds in the weight of a cord of dry southern pine pulpwood, or 50 pounds of dry pulp per cord. These values support the trend toward buying pulpwood by weight instead of volume.

At the Southeastern Station a study to compare increment core sampling methods for estimating tree specific gravity indicated that improvement in the accuracy of prediction is realized by taking at least two core samples and weighing them by the volume of wood they represent. Furthermore, the outer two-thirds of two increment cores provided a better estimate of specific gravity than the whole of a single increment core.

In a study of yellow-poplar at the Southeastern Station specific gravity increased with age through the first 20 years of growth, leveled off for a short period, and then decreased with age. Fiber length increased rapidly with age through the first 12 years of growth and then continued to increase rather slowly.

e. Log and tree grade development. The improved log grading system for ponderosa pine and sugar pine, reported last year, was put into Forest Service use in California. Other Forest Service Regions are taking steps toward use of the new system since it does a better job and is simpler to use than the four systems it replaces. Brochures and slide-tape lectures are available as aids to teaching the new grading system. Training aids are also on hand for the new southern pine log grading system.

For white pine, interim log grades were developed from studies in New England. These grades were satisfactorily tested on eastern white pine in Upper Michigan and North Carolina and will be tested in western white pine stands.

Lumber yield studies were made for log and tree grade development for several western softwood species; included were four studies of inland Douglas-fir, two of western larch and one of Engelmann spruce. Preliminary results indicate that improved analytical grades are needed to replace two arbitrary grading systems presently used.

Considerable progress was made in developing improved procedures for conducting lumber yield studies and analyzing their data. A procedure was devised for double-grading surfaced-dry lumber for determining the final grade and estimating the potential grade with manmade seasoning and manufacturing defects ignored. This principle may provide a useful tool for evaluating the efficiency of a commercial operation.

f. Lumber quality-yield development. An investigation of the clear-wood yield potentials of Standard grade (No. 4 Common) eastern white pine 1-inch boards demonstrated the possible application of cutting techniques commonly used with hardwoods to obtain clear pieces that could be rejoined with glue to make large clear boards. The No. 4 Common grade, containing knots, decay, splits, wane, and other imperfections, comprises about 50 percent of production in New England. The FPL study, in collaboration with the Northeastern Station, showed that potential yield could be estimated by a trained grader and that boards of the No. 4 Common grade yield a little more than half their volume in clear cuttings. On this basis, the value of the glued-up large, clear panel would more than offset the cost of the No. 4 Common lumber plus cutting and gluing costs. As a result of this investigation, the Department of Commerce authorized a loan for establishing a large mill to produce clear material from this low grade of white pine.

A Southeastern Station study of maple lumber showed a yield of clear cuttings of 56 percent from No. 1 Common and better lumber, and only 15 percent from No. 2 Common lumber. In the yield of total usable cuttings (clear, clear one face, or sound) No. 1 Common and better lumber gave 71 percent in total usable cuttings, and No. 2 Common lumber 61 percent.

At the Southeastern Station a method for theoretically sawing logs emphasized that lumber value per thousand board feet can vary widely for each log depending upon sawing method. Gang sawing produces widest boards without decrease in lumber grade. Cant width (when log is sawn to cants) also influences value yield. This theoretical sawing technique provides a new research tool for more comprehensive studies of the effect of decay, log diameter and log lengths on value of lumber from logs.

g. P.L. 480 - Peru. The project on the collection of wood samples and herbarium voucher specimens from the forest trees of Peru will provide needed information for developing a sound method of identifying Peruvian forest trees for the benefit of U.S. importers as well as Peruvian industry. Additionally, these data will broaden the basis for the establishment of an overall, worldwide system of wood identification.

Work is progressing well. About 375 trees have been selected and marked, and samples of leaves with flowers or fruit have been collected from nearly 200 of the trees. The work was reviewed on the ground by representatives of the U.S. Forest Service.

2. Solid Wood Products

a. Machining and veneer cutting. One of the most serious technical handicaps to the production of commercial Slicewood may be overcome by the finding in exploratory studies that flitches can be sliced into material essentially free from knife checks if first compressed. Even though recovery from compression was almost complete after release of pressure, the compressed flitches yielded 1/4-inch Slicewood entirely free of knife checks. This indicates that residual compression was enough to prevent formation of these hairlike cracks when the flitch was pressed against the nosebar of the slicer.

An exploratory study was completed under a grant to the University of Michigan on the potential of a device incorporating a recently discovered principle of physics known as a laser. Available lasers in the power range necessary for cutting wood require a synthetic ruby as the medium for stimulating and amplifying light. Lasers of this type thus far developed produce light in pulses rather than steady beams; the pulses can be focused with optical lenses. The study showed that the effect on wood is to vaporize it at the point focused upon to a depth of 1/32 to 1/16 inch. Repeated pulses deepen the hole. When a constant-beam laser of comparable power becomes available, it may prove useful for cutting and machining wood, since it could hypothetically penetrate a 30-inch log in less than 1/20 second.

Also, as a grant project at the University of Michigan, an investigation was begun of the utility of high-powered water jets for cutting and machining wood. Jets in the power range of 50,000 pounds per square inch with orifices 0.001 to 0.010 inch in diameter move water at speeds up to 3,000 feet per second. Maple up to 2-inches thick was cut satisfactorily. Although much research lies ahead before commercial use could become a reality, the study provides information basic to the establishment of feasibility when considering use of high-energy liquid jets for particular applications.

b. Produce and process development. An urgent marketing situation at Arizona and New Mexico ponderosa pine sawmills prompted a large-scale investigation of the possibilities of making various building components from low-grade material, including low-quality logs, log-grade boards, and shavings.

A number of products were made, several of them entirely new and novel. Taken together, the products comprise all essential structural components of a house shell. Moreover, all can be factory produced for rapid assembly on site. Included were vertically laminated members made by gluing boards together to serve as floor or roof beams. Boards were also used to make several types of house siding by covering the knots and other defects on one or both sides with resin-treated kraft, parchment paper, or vulcanized fiber. A flexible type of flooring, utilizing boards as the base for hardwood veneer surfaces, demonstrated another product for which the knotty ponderosa pine boards were considered suitable. Logs were also cut into veneer of two thicknesses. The thicker veneer was used as faces for a subflooring panel in which boards were used as the core material. The thinner veneer was glued together into three-ply plywood for use as underlayment for resilient-type finish floors. Shavings and flakes were converted into four types of particle board suitable for wall paneling and for concealed cabinet and furniture parts. Chips were bonded together to form the central layer of a three-ply particle board two inches thick, conventional flakes being used for the outer layers. This thick board was designed for use as door cores, interior partition, and roof decking.

Flat-pressed particle board has an inherent tendency to "spring back"--that is, to regain much of its original thickness--by swelling during exposure to rain or high humidity. This has been a major drawback to outdoor use of such particle board. It was found that steaming the board at saturation pressure and approximately 300° F. while it is still in the hot press induces plastic flow within the board, thereby relieving in the particles compressive stresses thought to be responsible for spring back. Normal shrinking and swelling tendencies of the wood particles are not greatly affected. The principle may also prove useful for other compressed solid wood products.

Recent studies of flake boards have reaffirmed previously developed relations between particle board properties and flake geometry, but the most significant finding was the outstanding performance of flake boards made from the low-density wood, kiri, from North Carolina.

Molding studies have shown a marked relation between properties in the molded particle and the original gross geometry of the wood particles before refining. It appears, however, that this relation is lost when the particles are fine enough to pass an 80-mesh screen.

Studies extending over several years were concluded on the effects of typical and modified planer shavings on particle board properties. In general, a modified planer head designed to produce shavings of best form for particle board was found suitable for typical products of a high-speed planer-matcher, such as studs, on which some surface roughness is not objectionable. For products requiring the best planing, a conventional planer head may be necessary for the finish cut, but preliminary cuts down to 1/32 inch of the final surface can probably be made with the modified cutter-head.

c. Wood drying. A continuous veneer dryer incorporating the "restraint" principle of veneer drying first announced at FPL in 1950, recently yielded highly promising results for drying hardwood veneers under conditions that leave them markedly more dimensionally stable than when conventionally dried. The principle involves high-temperature drying of veneer while it is restrained from shrinking by wire mesh screens. Commercial utilization of the restraint principle has awaited an economical continuous process. Recently, need for an effective method of continuous drying of southern pine veneer to reduce warping and splitting tendencies resulted in the devising of an experimental continuous dryer for studies with both hardwoods and southern pine.

Hardwood veneers of yellow-poplar and yellow birch were free of tension breaks and showed improved dimensional stability when dried under restraint. They were also flatter than matching veneers dried in a conventional roller dryer. Splitting resulted when enough pressure was placed on 1/8-inch southern pine veneer to achieve appreciable dimensional stabilization during drying. It was found, however, that drying at very low screen pressure produced well dried veneer that was flat and free of checks and splits although it shrank about as much as veneer passed through the conventional roller dryer. It was concluded that a redesigned dryer with small rolls in sufficient number to provide continuous drying for the necessary length of time might dry southern pine veneer 1/8-inch thick more smoothly and efficiently than existing commercial roller dryers.

Five years ago studies began using solar energy for drying lumber. These studies have demonstrated that the drying time for lumber can be reduced to about one-half that of air drying and that the quality is better. Research on more efficient designs for larger dryers is underway. FPL is collaborating with several field units in installing and operating solar dryers; one unit in Puerto Rico has successfully dried mahogany and yellow birch; research using lodgepole pine and Engelmann spruce is underway in Colorado; another unit is planned in Georgia. A commercial solar-drying installation has been made by a firm in Michigan. The Japanese Government has installed an experimental solar dryer in Tokyo.

Presurfaced hardwood lumber was shown to be much less prone to surface-check than rough lumber in kiln-drying experiments with red oak 1-1/8 inches thick. Neither surfacing nor wider spacing between boards appeared to affect drying rates appreciably. An experimental drying schedule somewhat severe in relative humidity induced checking in 32 percent of the rough-surfaced boards, while only 15 percent of those smoothly surfaced on both sides showed checks. Surfacing of the green lumber has further advantages because the reduced thickness results in a faster drying rate and increases kiln capacity, and uniformity of thickness curtails warp and final surfacing.

A study at the Pacific Northwest Station on the rate of drying and the occurrence of collapse in drying of green redcedar showed that development of collapse and honeycomb is intimately related to permeability. Also, honeycomb is associated with an erratic permeability gradient along the grain of given growth rings. Severe collapse may be related to low overall permeability.

d. Glues and gluing processes. During 1962, close relations with adhesive manufacturers that had been established with the 1960 FPL Adhesives Symposium continued to yield useful returns in the development of improved adhesives for wood-bonding. One promising formulation, a contact-bonding type, was successfully used for making stressed-cover house panels in a roller press that applied pressure for only an instant. The panels, with plywood and hardboard faces, were then installed in an experimental house for longtime durability evaluations. (See also IV, A-5-f.)

Another promising new industry-developed adhesive now under long-term durability study is a thermosetting vinyl emulsion. This formulation not only has the convenience of its general type for use in finger-jointed lumber and other glued wood assemblies, but shows great promise for exterior use as it has resistance in the boil-cycle test commonly used to evaluate exterior-type plywood.

Experiments with condensation products of alkaline bark extracts and formaldehyde yielded adhesives that were neither so strong nor so water resistant as phenol or resorcinol resin glues. Even as extenders, their possibilities appear limited so long as the price of phenol remains low. Commercial use of bark extractives for adhesives, therefore, appears to depend upon development of more fundamental knowledge of their chemistry.

Shrinkage and swelling can induce opposing stresses that can fracture a rigid glue. If an adhesive can undergo substantial deformation it can absorb differential stresses developed in the wood members it holds together. Ideally, the adhesive should be one with a modulus of rigidity approximating that of the wood used. Three adhesives known to have widely differing moduli of rigidity were used for making glue joints between plywood and softwood lumber typical of those in trusses with plywood gusset plates. One was an experimental epoxy-polysulfide with modulus of rigidity about the same as that of the lumber (much lower than that of conventional

wood glues); the second was compounded of similar resins but with a modulus about one-third that of the lumber; and the third was a resorcinol glue with a modulus 10 times that of the lumber. Exposure to severe cyclic changes from dry to humid conditions confirmed that joints made with the adhesive most closely approximating the rigidity of the wood sustained least loss in joint strength. Additional research is needed to fully evaluate the theory. Studies are also being carried on with adhesives that can deform adequately when subjected to opposing stresses in the wood members they join.

Continuing research on the gluing of wood treated with fire retardants uncovered two possible chemical causes of difficulties in producing strong joints in such wood with resorcinol and phenol-resorcinol adhesives. These glues are being concentrated upon because of their superior heat resistance. Chemical interaction between the fire retardants and the adhesive is now thought to be due either to an interaction of ammonium salts in the fire retardant with free formaldehyde in the resin, or to an acid-alkali balance at the wood surface that interferes with hardening of the glue. The formaldehyde-ammonia reaction is considered the more likely cause of difficulty.

Recent studies of the gluing of southern pine veneers show that conventional liquid phenol-resin glues, as now used in the western softwood plywood industry, produce plywood joints that meet current exterior test requirements; but that on southern pine plywood glues with greater water resistance than those commonly used for western woods are needed to meet interior requirements. Assistance is being given to both glue manufacturers and potential pine plywood producers in finding suitable gluing processes.

e. Glued wood products. Strong interest among several leading industrial concerns firmly supports estimates that during 1963 a promising new southern pine plywood industry will become a reality. Indications are that investments in plant and equipment will provide a market for southern pine peeler-quality logs totaling 75 to 100 million board feet annually in producing \$12 to \$15 million worth of plywood, with a \$10 million investment in plant and equipment. During the past year a broad field survey and additional studies in veneer cutting and drying were undertaken with special reference to the manufacture of sheathing-grade plywood entirely from rotary-cut veneer. This is the grade of softwood plywood now produced in largest volume. Aid was also extended the industry on requirements for structurally sound grades of plywood, and assistance was given industry and the Commerce Department in developing a commercial standard for southern pine plywood.

In studies to develop more efficient finger-type glued-end joints, tensile strengths in the area of 6,000 to 10,000 pounds per square inch were obtained in dense, straight-grained Douglas-fir. Strength values in the lower ranges were obtained with fingers only 5/8 to 3/4 inch long; the top of the range was attained with fingers 1-3/4 inches long or longer. These strengths are considered adequate for requirements in dimension lumber used for certain applications in structural framing. Such finger joints are much less wasteful of material and less difficult to make than straight-sloping scarf joints. Data are also being obtained to permit estimating the tensile strength of joints from the joint dimensions (length and slope of fingers, and fingertip thickness) for important structural species.

The method developed by the Forest Products Laboratory for evaluating the quality of glue joints of laminated members in service without destroying the timber was improved by a modification of the shear tool. Industry is strongly interested in this development as a practical quality-control procedure to assure satisfactory performance of laminated timbers.

f. Wood finishing. Basic research into the reasons why paints and other finishes sometimes deteriorate prematurely on wood, and to find ways of extending finish serviceability, opened several important new lines of investigation. A key study was one on physical properties of the wood surface as a substrate for finishes. It revealed the existence of high swelling strains concentrated at the interface between the summerwood and springwood of each annual ring. Differences in swelling between the summerwood and springwood are responsible, along with compressive stresses induced by planing. Premature peeling and cracking of paint occur over these lines of high strain.

Meanwhile, research was continued on the chemical and mechanical properties of films made from vinyl acetate and ethyl acrylate in various proportions aimed toward the synthesis of a copolymer with properties suitable for wood surfaces. Flexibility of the films was found to depend on thickness and chemical composition. Ultraviolet light lowered elongation. These findings demonstrate that much more needs to be known about the viscoelastic properties of polymers and the microcharacteristics of wood surfaces.

A study of the chemical changes brought about in wood surfaces by weathering got underway in cooperation with the National Lumber Manufacturers Association and the National Paint, Varnish and Lacquer Association. The photochemical effects of exposure of wood to ultraviolet light are being investigated by collection and analysis of the volatile decomposition products through gas chromatography or chemical analysis.

Final inspections of painted, paper-overlaid wood panels at the Madison exposure site showed that all types of paint gave better performance on paper-overlaid flat-grain lumber or plywood than on lumber without overlay. No decay was observed. However, about 5 percent of the painted southern pine board overlaid with resin-treated paper after 7 years of exposure in Mississippi showed extensive decay. There was no decay in painted boards that had no overlay. These observations strongly indicate the need for water-repellent treatment of overlaid material in the South.

In studies to evaluate the potential of new finishing systems, all systems of emulsion-type topcoat over an oil paint primer were heavily infected with mildew, although all paint systems contained fungicide. The type and amount of fungicide had little effect on resistance to mildew. This suggests that surface moisture content may be a controlling factor in mildew formation. Self-primed vinyl and acrylic emulsion paints were relatively free of fungus infection after 1 year.

After 1-year exposure, clear natural finishes of the oil-modified polyurethane-type are performing better than two different epoxy-type clear finishes on redwood and on softwood plywood. A porous latex paint on red oak, redwood, western redcedar, Douglas-fir, and mahogany became discolored when exposed to 90 percent relative humidity and 80° F., apparently by diffusion of extractives. The same paint applied to ponderosa pine, southern pine, and yellow-poplar showed no discoloration.

g. Fire performance of wood. Studies of the chemistry of the heat decomposition process have demonstrated that the most effective fire-retardant inorganic salts cause formation of more charcoal and less flammable tar than occurs in untreated wood. Apparently, this is due to the fact that decomposition begins at a lower temperature in the treated wood, setting up conditions that are more conducive to charring. As temperatures increase, charring continues and formation of combustibles is inhibited, so that decomposition and weight loss are greatly retarded.

The FPL-developed 8-foot tunnel furnace was used to compare surface flammability of Douglas-fir plywood treated with decorative and fire-retardant coatings and retardant impregnants. The decorative coatings did little to reduce flammability. The better fire-retardant coatings reduced flammability by 60 to 75 percent as compared with untreated plywood, and impregnation with monoammonium phosphate reduced flammability as much as 85 percent.

The old "rule of thumb" char penetration rate for wood exposed to fire, 1-1/2 inches per hour, is based on very limited research data. Char rate studies underway take into consideration species density, moisture content, and related factors. Relations are being sought between heat penetration rates, temperature gradients through the thickness of a member, and char depth properties, so that mathematical relations can be derived as aids in predicting performance of wood structures exposed to fire. For Douglas-fir lumber the temperature of the charring line has been established as 460° F.

Studies are being conducted using thermogravimetric, differential thermal, product analysis, and heat of combustion techniques to determine the mechanism of the combustion process for wood and also the mechanism by which chemical treatments improve the fire performance of wood. Thermogravimetric analysis has indicated that many, but not all fire-retardant chemicals lower the threshold decomposition temperature of wood. However, all fire-retardant salts are effective in increasing the char yield at the completion of the active pyrolysis. All inorganic salts so far studied appear to lower the activation energy for the pyrolysis reaction of wood to about the same extent for salts both effective and ineffective as fire-retardants. Differential thermal analysis of the combustion reaction of wood has shown decided separate exothermic peaks for both the flaming and glowing phases, and these phases have been closely related to corresponding exothermic reaction peaks for alpha cellulose and lignin. Fire-retardant chemical treatments diminish both the flaming and glowing peaks. Analysis of the char-tar-water-gas ratios in the pyrolysis of untreated and treated wood indicate an increase in the char yields and decrease in the yield of flammable tars when the wood is treated with inorganic salts, and this effect is much greater for effective than ineffective fire-retardant salts. However, the effect of concentration of chemical is not so great as observed in larger scale fire performance tests. Heat of combustion studies have indicated that effective fire-retardant salts reduce the amount of heat released during the initial stages of volatilization in the pyrolysis process.

Experiments conducted with many new organic fire-retardant chemicals intended for use with plastics and fabrics have shown most of them to be ineffective for use as fire retardants for wood with the exception of THPC-resin ((tetrakis(hydroxymethyl)phosphonium chloride)-methylol melamine-urea resin). THPC was developed by the Southern Utilization Division of ARS as a fire retardant for fabrics. Studies show that this water-soluble resin system can be impregnated into wood and polymerized to a water-insoluble, fire-retardant resin. The system may be suitable either as an impregnation or coating fire-retardant treatment for wood to be used in exterior applications. Specimens treated with 6 pounds of THPC resin per cubic foot of wood lost only about 25 percent of their weight during the fire-tube test as compared to about 72 percent weight loss for untreated wood.

h. Environmental effects. The significance of environment with respect to the serviceability of wood products under outdoor exposure received nationwide study during 1962 at weather exposure sites established the year before near Olympia, Washington, Fresno, California, and Gulfport, Mississippi. Each site was stocked with closely comparable specimens of lumber, laminated wood, plywood, and particle

board, as well as paints, natural finishes, preservatives, and wood glues of various types. These exposure sites, together with the one long maintained at Madison, Wisconsin, are coordinated so that reliable evaluation can be made of the effects of the four types of climate representative of the principal areas of the United States. A University of Wisconsin meteorologist is cooperating in development of special instrumentation needed to measure and record microclimate conditions at the four exposure sites--that is, actual temperatures, humidity, and associated conditions prevailing on the surfaces of and within exposed specimens.

i. Preservative development and treating processes. Treated posts installed in test plots continued to show that double diffusion imparts extended protection against decay and termites when applied to a species such as pine, providing the wood is completely immersed in the treating solutions. Results of short-term marine exposure tests of small panels indicate that the double-diffusion treatment is effective against limnoria, and may be useful in supplementing creosote. Periodic inspections of cooling tower lumber treated by double diffusion indicate continued effectiveness.

After several years' exposure, wood specimens treated to deplete their thiamine content showed no serious decay, but showed some evidence of surface soft rot; untreated specimens were destroyed by decay.

Further progress reports have been published showing the performance of numerous wood preservatives in stake and post installations. In stake exposure tests, ammoniacal copper arsenite and chromated copper arsenate appear outstanding among waterborne preservatives after more than 17 years. The Fairgrounds test track, near Madison, Wisconsin, one of three in cooperation with the Milwaukee Railroad, has been terminated after 46 years with average tie life varying from 6 to 12 years for untreated and 17 to 44 years for ties treated with different preservatives. Average life of treated ties in the Hartford, Wisconsin, test track, with somewhat less traffic, will exceed 50 years.

Pilot plant preseasoning treatments of green southern pine poles showed good protection for fungus control during one year after a 15 minute or longer immersion in high concentrations of ammonium bifluoride. Such treatments are now receiving consideration for commercial use. A study on groundline treatment of western redcedar poles, after four years' exposure in place, continued to show questionable need for supplemental treatment on butt-creosoted poles of that species. A preliminary study showed that a clean surface is much more difficult to obtain with Douglas-fir than with southern pine sapwood lumber pressure treated with pentachlorophenol water-repellent solutions. Results of pressure treatment of redwood lumber were considerably improved through the control of seasoning.

Estimated service life values have been determined for posts treated with 25 preservatives installed under three site conditions in 1936, and 45 preservatives and untreated controls installed in 1949. This study has contributed greatly to the recognition given standard wood preservatives, such as pentachlorophenol, Celcure, Osmosar, Tanalith, and Chemonite, and to the double-diffusion process. Among oil preservatives installed in 1936, 5 percent of pentachlorophenol continues to give outstanding service; for waterborne preservatives installed at that time, zinc meta arsenite, Celcure, and full-length copper and arsenic treatment by double diffusion rank highest in performance.

A study by the Pacific Northwest Station on extending the service life of utility poles made from thin-sapwood species showed that incising did not hasten the seasoning of poles before treatment. Untreated wood was detected at the bottom of a few checks after about 2 months of seasoning; in some cases, borings showed "white wood" to be beyond the solid penetration zone but within the selective ring-penetration zone. Although not conclusive, the percentage of "white wood" appeared to be greatest in unincised material and decreased with increased depth of incising. However, depth of penetration correlated more closely with depth of sapwood than with depth of incisions.

Service-life tests reported by the Southern Station show that many southern hardwoods, if properly treated with preservatives, will give long service as fence posts. Only the heartwood of Osage-orange, mulberry, and black locust served well without treatment. The tests showed that coal-tar creosote and pentachlorophenol gave good results when used to preserve posts of cottonwood, sweetgum, American elm, bitter pecan, green ash, overcup oak, honeylocust, mixed oaks, water oaks, and persimmon. Willow resisted the treatments and failed to give good service.

j. Sawmill improvement. The new FPL-designed inserted-tooth circular headsaw, called a "taper-tension" saw was given a preliminary trial. It has a strongly tapered plate profile, and uses teeth with a 7/32-inch kerf. The saw performed satisfactorily at feed rates up to 7-3/4 inches per revolution (carriage feed 360 feet per minute) on a 6-inch depth of cut. Also, work has progressed on the Duo-Kerf saw principle, developed some years ago at FPL, which incorporates alternate chipper and planer teeth. This arrangement of sawteeth produces a smoother cut than conventional teeth, for many purposes eliminating need for further surfacing. The Duo-Kerf principle has been successful in shop saws, and is now being restudied with a view toward making it more suitable for sawing logs. In trials under commercial operating conditions, the saw performed well on straight-grained logs. Changes in tooth geometry are being worked on to adapt the saw better to the cutting of logs with "wild" grain.

Experiments on the production of pulpable sawdust from red oak showed that pulp from sawdust produced by 1/4-inch bite per tooth was about equal in quality to pulp from conventional pulp chips.

The prolonged depressed lumber market has placed renewed emphasis on sawmill efficiency. The results of a Rocky Mountain Station study showed that the efficiency of a circular headrig mill can be improved by installing resaws. Operating time and sawing accuracy were improved. Grade recovery was little affected.

A mathematical study at the FPL of the relation of log diameter to saw kerf demonstrated that for small logs (diameters from 5-1/2 inches to 12 inches) width of kerf has a significant effect on yield of dimension lumber. The average yield increase was slightly over 7 percent for sawing with a 9/32- rather than a 12/32-inch kerf. The study also showed that if logs are carefully segregated by diameter into product groups, recovery gains of up to 15 percent can be realized regardless of kerf width used in sawing.

An evaluation was made by the Southeastern Station of a modified "stepsaw" developed by J. T. Griffin of Valdosta, Georgia called the "Griffsaw." The production rate of the prototype model was about 7,000 board feet per hour. Lumber cut was fairly uniform, the kerf is saleable for pulp, and the machine can be used with saws cutting a narrow kerf. Although 3/16-inch bits were used on the test model, no trouble has been experienced in other trials with saws cutting a 1/8-inch kerf.

k. P.L. 480 - Finland. A study on factors affecting the impregnability of wood is located at the State Institute for Technical Research, Helsinki. Work in the first 2 years was largely on field studies such as effects of wet storage and drying methods on penetrability. Greater emphasis is now being placed on fundamental principles such as the significance of pectin, proteins, and resin substances on penetrability.

3. Wood Fiber Products

a. Pulping process investigations. As first reported last year, polysulfide pulping is under study to increase the efficiency of the basic kraft (sulfate) process for southern pine. Polysulfide is in effect a sulfur-rich form of sodium sulfide containing one to four or more atoms of sulfur per molecule. Sulfur is a key ingredient of the pulping liquor for solubilizing lignin quickly and with relatively mild action to reduce loss of cellulose and hemicellulose. Yield of kraft pulp was increased 20 percent or more when 20 percent of polysulfide sulfur (based on the weight of the wood) was added to the cooking liquor. This represented a substantial improvement in yield over results previously reported. Progress was also made in raising the yield at a given polysulfide level and otherwise improving the efficiency. Lower cooking temperatures increased effectiveness. The selectivity of delignification was found to be due to protection and retention of the hemicelluloses. The yield is increased mainly because of greater retention of glucomannan, accompanied by small improvement in yield of xylan and cellulose. Work is continuing to obtain data needed to determine the technical limitations as well as the possibilities of recovering the chemical for reuse. Practicality of the process is, of course, contingent upon development of an efficient recovery system, which remains to be done.

Use of the multistage sulfite process was evaluated for Douglas-fir, a species difficult to pulp by the conventional sulfite process. By appropriate control of the pH in each stage, considerable increases in strength or yield were obtained. Strength comparable to that of kraft pulp, however, was obtained only by a more drastic treatment in the alkaline sulfite second stage than is needed with other wood species that have been tried. Tearing resistance similar to that of kraft was also afforded by the single-stage alkaline sulfite process. The substitution of sodium sulfide for caustic soda as alkaline buffer in this process greatly increased the rate of delignification and improved the selectivity of the pulping reaction.

Yield of spruce pulp was raised about 10 to 15 percent by adding 0.5 to 1 percent (wood basis) of sodium borohydride to single-stage, alkaline sulfite cooking liquor. The gain was attributed largely to increased retention of glucomannan; strength loss was only moderate. Other studies showed that, among various alkaline liquors, a combination of sodium sulfite and sodium sulfide was most selective in removing residual lignin from high-yield spruce bisulfite pulps, but generally resulted in appreciable loss of carbohydrate yield. Use of 0.2 to 0.4 percent sodium borohydride effectively retarded the carbohydrate degradation. The objects of this work are to raise tearing resistance of softwood sulfite pulps to that of kraft pulps, to improve pulp strength, and to reduce bleaching chemical requirements.

Most of the chemical pulping processes use the compounds of sulfur and sodium and the recovery of these cooking chemicals from spent liquors is relatively complex and costly. The chemistry and interconversion of sulfur compounds are complicated and not completely understood. Research in these areas was stepped-up in an effort to obtain more intimate chemical knowledge which might lead to the development of

simple chemical recovery systems, for example, for the neutral and alkaline sulfite pulping processes. Preliminary results indicate that the direct conversion of neutral or alkaline sulfite smelt for the recovery of cooking chemicals may be feasible.

b. Pulp properties. Microscopical studies of individual fibers and fiber sheets with visible, ultraviolet, and fluorescent light and the electron beam are broadening understanding of fiber bonding. For example in studies dealing with efforts to improve resistance to compression of container board under high humidity by use of chemical additives, it was found that when a starch-phenol resin was added to relatively dry board at the size press on the paper machine, a considerably higher strength was obtained than when the chemicals were added to the wet board at the smoothing press. Microscopical examination showed that the chemical penetrated only a little way below each surface in the stronger board, but that penetration was essentially uniform in the weaker board. The partially penetrated boards act like sandwich constructions, the resin-coated layers of fibers on the two surfaces acting as "skins." In another study of size-press sizing with starches and starch-protein combinations, microscopical examination showed that variations in the amount of sizing chemical picked up were due to the presence of casein, and not to variation in the viscosity (average degree of polymerization) of the starch as had been assumed previously. In other research, microscopical studies of fiber structure as related to physical changes that occur during beating showed that kraft pulp fiber is resistant to mechanical action; this explains, in part, why kraft pulps are generally stronger than acid sulfite pulps.

For many years, an important market for wood pulps has been in the manufacture of rayon, cellophane, explosives, plastics, and sizing or coating agents by chemical reactions such as esterification and etherification. More recently there is considerable interest in a type of conversion called grafting to produce cellulosic materials with new and different properties. Studies of grafting acrylonitrile onto cellulose with unbleached southern pine kraft linerboard, bleached softwood sulfite computing machine card stock, and hardwood kraft pulps showed that the grafting reaction was affected by presence of lignin. Effects on the linerboard and card stock included increases in important properties such as dimensional stability at high humidity, resistance to compression, and resistance to rot. Depending on the type of grafting, it was found that other improvements can be obtained, such as in folding strength, dyeability, and affinity for certain resins and coating agents. Uses for these types of treated pulps, possibly for such things as filter materials, have not yet been well explored, but offer interesting possibilities.

c. Fiber processing. Earlier experiments of mechanical processing of pulp for papermaking showed that various changes occur in the fibers, including a reduction in their length. Studies on the use of a small Claflin refiner have shown it to be superior to a beater and jordan in preserving fiber length and, hence, tearing strength while developing other strength properties. A comparison of the Claflin refiner with a disk refiner for processing of sweetgum and softwood kraft pulps showed them to be about equally satisfactory.

Expanded uses of the higher-yield pulps would be possible if they were brighter in color or could readily and economically be brightened to levels required in white papers. Studies of the three-stage bleaching of a hardwood neutral sulfite semi-chemical pulp, with particular emphasis on the chlorination stage, resulted in a better understanding of the effect of variables upon rates of chlorine consumption, relative amounts of materials removed by the chlorination and extraction stages, and pulp properties.

Nonchlorination bleaching appears to be the only type of bleaching that causes little or no loss in yield with higher-yield pulps. Nonchlorination bleaching of balsam fir sodium bisulfite pulps (yields from 61 to 94 percent) resulted in more favorable brightness gains than those reported by other workers for pulp made from spruce. For example, the use of peroxide and hydrosulfite in one-stage treatments produced near-normal brightening effects. In successive treatments these chemicals produced brightnesses up to the desired level of 75 percent, but chemical requirements may prove excessive.

d. Papermaking processes. A discovery reported last year, that restraint during drying results in a stiffer and more dimensionally stable sheet of paper, was further investigated. Improved sheet stiffness holds prospects for stiffer structural types of paperboards; better dimensional stability is important in map papers, color printing papers where color register is critical, and sorting-machine and computer punch cards. Continuing experiments have thrown considerable light on causes of differences in tearing strength, stiffness, and dimensional stability of papers in the machine and cross-machine directions of the sheet. Curved expander rolls on the paper machine have been found to widen the sheet as it is formed, thus counteracting shrinkage. Sheet stiffness in the cross-machine direction was increased about 30 percent with two expander rolls contacting the sheet when its moisture content was about 50 percent. Significant gain in dimensional stability was achieved when two expander rolls were placed in the wet press section. Results of the experiments have excited wide interest in the industry.

The relation between density and stiffness of paper was found to vary with the densifying and the drying method. Wet pressing substantially increased the modulus of elasticity while dry pressing (calendering) increased the modulus only in proportion to the thickness change.

Investigations involving the improvement of corrugating medium showed that washing of the pulp prior to refining gave an improved crushing strength. Higher-strength corrugating medium was obtained from pulp refined in a disk mill than in a jordan. Cooked starch added at the size press and carboxymethylcellulose added at the smoothing press produced a satisfactory 42-pound linerboard from waste corrugated boxes. Starch added at the smoothing press gave only a slight improvement. The flat crush resistance of combined corrugated board and that of the corrugated medium were increased 50 percent with treatments of 1 percent of carboxymethylcellulose or 2 percent of starch applied at the size press to the corrugating medium. The high water absorption rate of cold soda medium was reduced by 50 percent with the starch application and by 80 percent with the carboxymethylcellulose. The treated media corrugated satisfactorily at speeds of 50 feet per minute, with no visible cracking or difficulty in bonding to kraft liner.

Studies aimed at increasing the use of hardwoods in offset papers showed that mixed hardwood kraft pulps could be used to replace mixed hardwood semichemical pulp without affecting the strength of the offset paper. More opaque papers were obtained with hardwood kraft pulp containing a substantial amount of oak than with either semichemical or kraft pulp containing a small percentage of oak. The oak, however, had an adverse effect on pick resistance.

A study of the use of ponderosa pine groundwood in a bleached household towel showed that creped toweling paper made from a mixture of equal quantities of bleached ponderosa pine groundwood (a much higher proportion than is customarily used in this grade) and bleached western softwood kraft had strength and absorbency equal to or better than four representative commercial household towels. Softness of the study

towel was equal to the softest commercial towel and was improved when the towel was embossed. Experimental toweling containing 65 percent of ponderosa pine groundwood also had adequate strength, good absorbency, and softness, but it was not as bright as commercial toweling.

Tempered hardboards made from mechanically fiberized chips of white oak and Douglas-fir without resin addition and without heat treatment were relatively weak and had very poor water resistance. Heat-treated boards containing 1 to 2 percent of resin were of acceptable quality. For areas in which stream pollution is a problem, the effluent will contain less solids than when current methods are used, and the yield of pulp from disk-milled chips will be higher.

4. Wood Chemistry

a. Wood carbohydrates and conversion products. Wood hemicelluloses, representing up to 30 percent of the carbohydrate content of a tree, include those sugar polymers which are unique to plant residues and thus have high potential value as raw materials for chemical conversion processes. The hemicelluloses also are of primary concern to the pulp and paper industry as their retention in pulp fibers greatly improves fiber to fiber bonding during sheet formation as well as adding measurably to pulp yield. In an initiating study of this important group of carbohydrate materials, xylose-containing hemicelluloses have been isolated from fresh aspen wood both by direct alkaline extraction and by a combined delignification and extraction with a nonreactive solvent. The latter provides an acetylxylan believed to have the same structure as in the original wood. Further fractionation of the two xylans was made on the basis of solubility characteristics. Acid hydrolysis of the various fractions, followed by quantitative analysis of the hydrolyzates using chromatographic techniques now under development, will provide the basis for structural characterization. Similar techniques applied to the other hemicellulose constituents should eventually lead to the attainment of the long-range objectives established for this work.

The inability of ordinary reagents to penetrate the highly ordered crystalline structure of wood cellulose has proved to be the economic barrier to chemical utilization. Attempts to modify this crystalline structure so as to enhance chemical reactivity, although technically successful, have proved too costly for commercial application. Work initiated during the year indicated that the heat treatment of wood cellulose at temperatures of 180° to 240° C. provided a definite increase in hydrolysis rate and sugar yield. Extension of the work to include a study of the combined effect of heat and electron irradiation on the saccharification process showed that while the combined heat and irradiation treatments were essentially additive in their ability to enhance cellulose saccharification, the benefits obtained were not of sufficient magnitude to be of commercial interest. Irradiation alone at high-dose levels (10^5 to 10^8 roentgens under a potential gradient of 8 million volts) gave dramatic increases in both hydrolysis rate and sugar yield. Although the economics of such radiation levels are not favorable at the present time, the rapid rate in the technological development of radiation equipment holds promise for the future.

b. Lignin structure and utilization. During the year, applied research was resumed on lignin after a lapse of some years. The problem selected was the alkaline hydrolysis to phenols and other chemicals of waste sulfate pulping liquors. This appears to be a promising approach, since in this process the lignin is already collected in concentrated form and phenols are relatively high-priced products. Efficient means of carrying out the experimental digestions and of characterizing the products have been worked out.

In basic studies, procedures for investigating the distribution of lignin in the cell walls of wood have been extended to include the staining of the lignin, in situ, with compounds which will selectively react with the lignin and, in addition, absorb the beam of the electron microscope. Using these new approaches, the concentration of lignin in both softwoods and hardwoods in the region bordering the cell cavity has been substantiated. Important procedures in structural studies and evaluation of lignins, and a new degradative method involving the cleavage of lignin into fragments, now developed, offer further promise of advances in basic chemical knowledge of lignin. In model studies, so-called because they start with compounds that contain portions of hypothetical lignin structures, the dehydrogenation of phenols was found to give, in addition to the previously reported biphenyl linked compounds, considerable quantities of secondary substances. Since similar structures are likely to occur in lignin, isolation and characterization of these secondary substances are expected to lead to other important advances in characterization of lignin. This continuing accumulation of basic facts about lignin is fundamental to more profitable and widespread uses of this abundant natural material.

c. Chemistry of wood and bark extractives. The bark of a few tree species has been used as a source of chemicals for a long time. Leather tanning agents are still obtained from hemlock and some other species, and cork is a well-known bark product. Redwood bark fiber is used in insulation. On the whole, however, bark is generally discarded or, at best, used for fuel at mills where it accumulates.

One reason for such limited use of a raw material that is widely available is that the chemistry of bark is little known. Research on fundamental bark chemistry has in recent years been accelerated at FPL to provide the essential information that is obviously needed as a foundation for broad utilization. Significant progress has been made during the past year in studies on the extractives of heartwood, bark, and pine pollen and in the field of naval stores.

Interesting compounds have been isolated from two tropical hardwoods, Cordia trichotoma, and Vitex lucens; and red elm. Veneer of the first wood deposited a mat of feathery white crystals on the surface on drying. These crystals were identified as a mixture of isomeric eudesmols, sesquiterpene alcohols more commonly found in eucalyptus. Commercial utilization might be possible since the material is fairly pure and is a component of certain perfumery oils. The second wood has been found to contain unusual flavonoid glycosides. The third wood contains a yellow compound responsible for discoloration in furniture finishes. It has been isolated and partially characterized, and appears to be an unusual phenolic compound.

The benzene extracts of the bark of several softwoods, including jack, loblolly, sugar, lodgepole and western white pine, and Pacific silver fir, have been under study. Most interesting has been the discovery of the presence of a series of new and unusual triterpenes, a class of compounds not usually found in softwoods and which are related biochemically to the physiologically active steroids. The pine triterpenes all appear to be related to pinusenediol, the new triterpene which was found previously in jack pine bark, and whose structure FPL scientists hope to elucidate. Jack pine bark has been most thoroughly investigated; over fifty compounds have been separated so far. Lodgepole pine bark is unusual in that over one-fourth of the bark is soluble in benzene. One constituent is manool, an unusual diterpene alcohol used commercially in perfumery.

Research on pollen extractives, especially from loblolly pine, has resulted in the isolation and identification of a variety of chemical compounds which may have chemotaxonomic significance and add considerably to the knowledge of the chemistry of this little-studied important material.

Considerable progress has been made also in setting up certain research in the field of naval stores. In anticipation of changes in the supply base for naval stores from stump wood to gum and tall oil supplies, research is being carried on in cooperation with the Pulp Chemicals Association involving fundamental studies on the basic nature and composition of pine wood extractives, their role in the physiology of the tree, and on the changes induced during commercial pulping operations. Analytical procedures under development will have broad application in both fundamental and applied research.

d. Biochemistry of wood constituents. A study to develop methods for the production of arabitol by osmophilic yeast fermentation of the simple sugars produced from wood by acid hydrolysis was completed. Endomycopsis chodatii can produce arabitol in yields of 35 percent based on sugar used. Glucose and mannose are efficiently used for yeast growth and arabitol production, while galactose, xylose, and arabinose are utilized slowly and only for yeast growth. By the use of synthetic medium developed for this organism, it was demonstrated that the culture does not require organic nitrogen and that vitamins are not essential. Yields of arabitol from these larger sized fermentations are comparable to those obtained in shake flasks. This completes work on the production, by fermentation, of three closely related polyhydric alcohols, glycerol, erythritol, and arabitol. Fermentations are brought about by various species of yeasts isolated from natural products, and yields of from 35 to 40 percent by weight of the sugars used can be obtained. Erythritol and arabitol are not now industrial products but could be produced at a reasonable price if a demand develops.

With the exception of yeast production, the above fermentations make use of only the hexose sugars. Since the pentose sugars are an important part of the yield from wood hydrolysis and, if not used, are an economic loss, an organism was sought that would produce a useful product from both hexose and pentose sugars. A mold was found that would produce itaconic acid from both types. Its main use is in the production of polymers by polymerization through the double bond or by the formation of esters or amides through the carboxy groups. Fermentations made with the mold have resulted in yields of 50 percent by weight of itaconic acid based on glucose, while yields from xylose are lower, being of the order of 40 percent.

e. Surface and polymer chemistry of wood. Studies of surface and polymer chemistry of wood deal principally with two surface chemistry factors, adsorption of polymers and surface stabilization. The polymer adsorption study has as one object the gathering of data on factors that contribute to or detract from surface adsorption. The stabilization study, begun during 1962 in cooperation with the National Lumber Manufacturers Association and the National Paint and Varnish Manufacturers Association, is designed to produce basic information on the requirements for surface stabilization against swelling and shrinking, with the object of improving finish-holding properties for coatings such as paints and varnishes.

Surface adsorption experiments with polyvinyl acetate showed that there is a marked difference in adsorptive capacity between the two main components comprising the total external surface of wood. The portion comprised of exposed lumen walls (49 to 90 percent of the total, depending on species) is much less adsorptive than the portion consisting of cut and exposed wood substance within the cell walls. Certain swelling pretreatments accentuate these differences in adsorptive capacity to more than tenfold. From these findings it was concluded that the chemical composition of the immediate surface of the lumen walls differs considerably from the usual carbohydrate-lignin complex of wood substance.

Exploratory studies showed that surface swelling and shrinking can be substantially reduced by surface stabilization. Diffusion characteristics of different stabilizing chemicals into the side grain of wood are being systematically studied to uncover factors that influence the development of shrinkage stresses near the surface during drying.

f. Process development. With any scheme for economical conversion of low-grade wood residues to organic chemicals in significant quantities, the problem arises of separating wood components or their products. Work has continued on investigating the mechanism of these separations in two major areas: (1) delignification and hemicellulose removal, and (2) saccharification. One study of xylan removal showed that the solvent character of the solution is a very important factor.

The saccharification problem is perhaps the most important part of the project. Studies designed to attack this problem have shown that sweeping generalizations about destruction rates of sugars in dilute acidic medium may be made; also, the stability of various sugars in many different media may be determined by obtaining only a minor amount of experimental data. Further work on the degradation of sugars in strong acid medium is planned and may lead to the making of similar generalizations. If so, the work of selecting suitable saccharifying reagents will be simplified.

Work on the development of a method for charcoal quality evaluation consisted of determining the electrical resistivity values in the longitudinal fiber direction for four charcoals from different woods conditioned to about 10 percent equilibrium moisture content. These initial values show a resistance-volatiles relationship in which there is marked increase in resistance with increasing volatiles content. At similar volatiles levels, species resistances differ in the order of tenfold.

Further work in the field of wood carbonization at the Lake States Station showed that average ignition time to produce satisfactory draft conditions in charcoal kilns was reduced from 90 minutes in natural draft kilns to 1 minute in a stack-draft kiln, with coaling time reduced by about 30 percent. There was also a slight increase in charcoal yield from green sugar maple slabs and stovewood.

g. Analytical development and instrumentation. The availability of precise analytical techniques is a major key to progress in any field of research. It is of special significance in wood chemistry, where the great diversity of chemical constituents both contained in and desirable from wood and wood residues creates the need for equal diversity of measuring techniques. Recognizing this need work was started to perfect accurate means for the quantitative separation and analysis of mixtures of soluble organic components on a rapid and routine basis by use of thin-layer chromatography. FPL paper chromatographic procedures have been accepted as an ASTM tentative standard method. Thin-layer chromatography is a new development which, because of its greater speed and sensitivity, promises to become an important laboratory tool. The Laboratory plans to maintain a leading position in this area of analytical development.

h. P.L. 480 - Finland. Accessibility studies of cellulose fiber are underway at the State Institute for Technical Research, Helsinki. Dr. Ant-Wuorinen, the scientist in charge, is making good progress. Thus far, effort has been directed primarily toward acquiring knowledge on formation and behavior of functional groups in cellulose. His first publication under the project, a compilation of four research papers, concerned a new proposal for X-ray diffractometric determination of the crystallinity of cellulose. His findings represent solid advances in this highly complex area of basic research.

Another Finnish project in the field of wood chemistry, located at the College of Agriculture and Forestry, University of Helsinki, involves the aerobic bacterial degradation of lignin. This project is progressing extremely well. Publication of results of some aspects has been made through Finnish Technical Journals. As a part of the grant, Dr. Sundman, the project leader, visited this country in the summer of 1962. The contacts made will be valuable both to her and to our scientists.

5. Wood Engineering

a. Fundamental wood properties. Reevaluation of species strengths begun with white fir in 1961 was extended to western hemlock during 1962. This work is another phase of the quality assessment of standing timber by means of increment cores described under Wood Quality Research (IV, A-1-d). As with white fir, alternate logs from the same western hemlock trees were sent to FPL and the Tacoma, Washington Laboratory of the Douglas Fir Plywood Association (DFPA). DFPA, one of the supporters of the over-all western timber quality census, is evaluating the strength of plywood made from veneer of those logs for correlation with FPL data on strength of clear wood. An increase of about 6 percent in modulus of elasticity of green white fir found in FPL studies is not likely to materially change the present species groupings with respect to stiffness ratings for joists, rafters, beams, and similar structural parts. Results from work underway on western hemlock from northwestern and southwestern Oregon and central Washington are not yet sufficiently complete to enable comparison with published values.

Under arrangements with the Pacific Northwest Forest and Range Experiment Station and Oregon State University, random sampling techniques for western hemlock are being studied to find means of sampling for strength and related properties more efficient and less costly than those long used, based on standard methods of the American Society for Testing and Materials (ASTM). Encouraging results are being obtained.

Other basic strength studies included one on redwood and another on several Hawaiian species. Among the Hawaiian woods under study in cooperation with the Pacific Southwest Forest and Range Experiment Station and the State of Hawaii, Eucalyptus saligna was shown to have strength properties generally similar to those of the same species grown in Australia and to those of pecan hickory. Silk oak (Grevillea robusta), evaluated as a furniture and cabinet wood, exhibited hardness and density generally comparable to those of paper birch but shrank less, being more like black cherry in this property. Veneer cutting and machining evaluations are also contemplated.

Young-growth redwood is increasingly being utilized by industry. From material obtained with the aid of the California Redwood Association, FPL is evaluating strength properties of material from several locations. Increment cores were obtained to furnish additional data on the relationship, not yet analyzed, of increment core density to overall density and properties of the trees.

Closer calculation than hitherto possible for fatigue strength appears as one significant result of a limited study of the effects of knots, drilled holes, and sloping grain in quarter-scale bridge stringers under repeated flexure. Strength-reducing effects of a 1-in-12 slope of grain and knots in the area of maximum tensile strength were shown to be cumulative under such repeated loading. In grading such structural members, this effect can be compensated for by applying a strength ratio that is the product of the strength ratio for slope of grain and that for knots.

The effect on physical and mechanical properties of fire-retardant treatments is under study to meet design needs resulting from pronounced increases in the use of structural members so treated. Previous investigations had indicated that treatment causes some decrease in flexural strength properties, but the nature of the effect or the factors primarily responsible remain uncertain. This comprehensive basic investigation is supported in part by the National Lumber Manufacturers Association, the American Wood Preservers' Institute, and the American Institute of Timber Construction. Preliminary results indicate that the strength-reducing effect depends upon several factors that include the chemical used, its concentration in the wood, treating conditions, and use conditions. Several chemicals used commercially increase the normal tendency of the wood to absorb moisture. Wood treated with these chemicals shrinks less at all equilibrium moisture content levels, but species differ. Treated ponderosa pine, for example, is more hygroscopic than treated oak, but shrinks more.

For most efficient engineering use of wood, it is necessary to be able to determine nondestructively the mechanical properties of individual pieces. Research in progress is evaluating possibilities and limitations of various approaches. Vibration studies of small specimens and material of commercial size indicate that the natural frequency of a wood beam in flexural vibration may be an effective indicator of its stiffness and some of its strength properties. The relationship between static and dynamic properties for softwoods does not appear to be basically different from that for hardwoods. Research involving transmission and backscatter of nuclear radiation by wood demonstrated that it may be possible to determine density and moisture content and to detect voids in wood by this method. However, the results indicate that there may be difficulties in applying such methods to thin material and at rates needed for production use unless overcome by improved instrumentation. Progress has been made in planning a symposium on nondestructive testing of wood to be held at the Forest Products Laboratory in October 1963.

b. Properties of wood-base and related materials. The extensive 4-year investigation of fundamental mechanical properties of hardboards described in last year's report is proceeding with materials furnished by the cooperator, the American Hardboard Association. Under study are plastic and elastic behavior, effects of duration of stress, fatigue and rate of loading, and time-temperature-moisture content relationships. This research will provide a more scientific basis for structural application and other broadened uses. Concurrently, coordination of Commercial Standards proposed for several wood-base materials was undertaken, in cooperation with interested industry groups, for the Commodity Standards Division of the U.S. Department of Commerce. Included are hardboard, garage doors with hardboard panels, mat-formed wood particle board, and extruded particle board.

c. Analytical mechanics. A theory of orthotropic elasticity has long been applied with signal success to study the different mechanical properties of wood associated with each of three mutually perpendicular directions. When attention is focused upon a point in the material, such as the determination of a stress concentration, or upon the equilibrium of a very small part of a much larger volume of the material, the use of infinitesimal calculus may have to be replaced by the calculus of finite differences in order that the mathematics will agree with experiment. It is not intended, however, to abandon the infinitesimal theory where it is useful. This is illustrated in a study in which the usual engineering methods have been expanded to allow the calculation of the reactions of any wood highway bridge, thus greatly reducing the necessary amount of experimental work.

Other studies have led to the development of mathematical formulas that give the deflections of beams made from reinforced plastics (Economy Act cooperative research). These formulas show that the stiffness of the beams is less than that calculated by means of the unmodified elementary analysis because of displacements of the fibers with respect to the plastic. The same analysis, with certain amplifications, can be applied to wood considered as a matrix reinforced by fibers; thus the relative movement of the fibers in wood can be taken into account.

1. Research equipment and method development. Precise measurements of loads and deformations are a vital part of wood engineering research to reduce costs, conserve manpower, and avoid cumbersome field trials.

A device consisting of a versatile hydraulic system of jacks and structural steel framework was developed to measure loads in a highway bridge study. While the loading framework was especially designed for this experiment, the technique can be applied to a wide variety of structural evaluations. An extensive study to establish engineering properties of hardboards required the development of automated, efficient strain-measuring apparatus for appropriate mechanical tests. Deformations gages were designed, constructed and perfected to meet the requirements for accurately measuring deformations. Mechanical property determinations can now be carried on by one person who operates the universal-type test machine and its automatic recorder.

e. Design criteria. Application of rigorous design criteria based on material properties and theoretical analyses permits more efficient use of materials. As costs of material and labor rise, advances must be made in greater utilization of raw materials so that industry can survive competition. For example, studies on the use of adhesives or mastics instead of nails for container fastenings have demonstrated that smaller box ends can be utilized and that perhaps a mechanical device can be contrived to assemble boxes with adhesives, thus lowering box costs. The proper system for joining box parts must be carefully chosen so that good performance is assured. Another study disclosed that the performance of laminated members of coast-type Douglas-fir as structural members of naval vessels was equivalent or superior to beams of white oak under repeated bending loads after various exposure conditions. Other studies of glued laminated wood beams with prestressed steel wire cables showed that such beams can carry larger loads than beams not prestressed, and a more reliable prediction of ultimate load can be made for the prestressed beam. The work indicated that greater increases in strength resulted from use of the reinforcing steel strands in beams made of the lower structural lumber grades. Prestressing was accomplished by a tension force on the steel strands inserted in prepared holes in the tension portion of the beam. The induced bow puts under compressive stress the portion of the beam that in service would be under tensile stress. In effect, an increase in allowable load is possible because of additional load needed to flatten the prestressed beam. Major benefit could accrue to the laminating industry.

f. Structural utilization. A landmark in housing research was appropriately recognized when several stressed-skin wall panels were removed from one of FPL's two 25-year-old prototype prefabricated houses for reevaluation. Bending strength of the wall panels was found to be virtually unaffected by the quarter century of service. Joints between panels were clean and free of deterioration. The panels were replaced with new ones in which a contact adhesive was used to bond the plywood skins to the framework. Pressure was applied with a roller press through which the panels were passed. Such adhesives were not available when the original panels were made. (See also IV, A-2-d.)

In the studies to evaluate performance characteristics of wood bridges, loads were more uniformly distributed among the stringers than is recognized in bridge design formulas now commonly used. Arrangement and nailing of 2- by 6-inch decking appeared to have little effect on load distribution. Loadings that caused bending failure in the stringers were great enough to assure at least adequate margins of safety, provided the timbers used have been carefully graded according to recognized principles of structural grading. Also, renewed interest in structural grades of hardwood timbers prompted the development of a simplified system of structural grades by FPL at the request of the National Hardwood Lumber Association for possible incorporation in their grading rules.

g. Packaging. Research on packaging at FPL has long had substantial military support, and more than one-half of it continues to be done primarily for various branches of the Department of Defense. Much of this work, of course, has broad application. For example, a current study of double-wall corrugated containers supported by the Air Force may lead to greater allowable loads under freight classification rules. Research has continued in an effort to improve top-to-bottom compressive strength of fiberboard containers under high humidity conditions. The problem is being attacked in two ways: (1) by additives to the fiber in the paperboard, and (2) by attempting to incorporate veneer into the liner-corrugating medium assembly. In the latter, a combined experimental packaging material was produced on an exploratory basis and results encourage further work on the project. The product consists of two sheets of single-wall corrugated material combined with a sheet of veneer as the middle liner in a double-wall fiberboard structure. Another approach to the improvement of stacking characteristics that appears to have excellent potential is a box consisting of three parts. One piece forms the main body, top, bottom, and sides; the ends are open. Two end pieces, the edges of which are folded back, slip into the end openings and are fastened by staples or glue. The recessed end pieces leave rims that serve as handles and strengthen all eight corners of the box to improve stacking strength. Under humid conditions wood end blocks could be inserted into the recesses to further bolster stacking strength.

A comprehensive cushioning design handbook was completed for the Air Force Packaging Laboratory, Brookley Air Force Base, Alabama, along with a "cushioning selection indicator," to be used for solving cushioning design problems. These two items, based on the most comprehensive research data available in the cushioning field, will provide for effective determination of the thickness and kind of cushioning material necessary to protect fragile items under a wide variety of conditions.

Another packaging study showed that low-density hardwoods such as aspen, make good pallets when a modified design is used. For example, full 1-inch-thick deck boards instead of nominal 1-inch lumber, used with longer nails, produced pallets comparable in rough-handling performance to hardwood pallets made from higher density species. Use of this design data can extend the utilization of aspen lumber in many parts of the country.

h. P.L. 480 - Finland. In a project located at the State Institute for Technical Research, Helsinki, on moisture-temperature-time-strength relations for Scots pine, Norway spruce, and European birch, delays in perfecting equipment and in obtaining technical employees gave the project a late start. Research accomplished thus far has been of a preliminary nature.

6. Regional Utilization Problems

A national research program necessarily is made up of those regional and interregional problems which have national significance. Since 1944, the Forest Service Forest Products Utilization Research program has been guided and serviced by small, grass-roots staffs of well-qualified forest products technologists located at the Forest Experiment Stations. Now established as Divisions of Forest Utilization Research at each Forest Experiment Station (except Northern) and the Institute of Tropical Forestry, these staffs contribute to the Forest Products Utilization Research program in many ways. The sum total of these contributions has been to make the Forest Products Laboratory more responsive to regional needs and to make more effective application of research results and improved local effectiveness in solving regional problems. The details of actions and accomplishments by the Station FUR Divisions during the past year can be only touched upon here. A few are given as illustrations:

a. Regional problem analyses. In the Central States, substantial improvement in use of sawmill waste by debarking logs and chipping residues for wood pulp was found. A major problem is utilization of the large volumes of lower grades of forest raw materials and lumber produced at the sawmills. Quality hardwoods are no problem--veneer logs and the upper grades of lumber are in strong demand. Recommendations for increasing the use of lower grades of trees and lumber include: (1) development of new products and evaluating the suitability of hardwoods for old and new products; (2) upgrading low-grade woods by improved, simple manufacturing procedures; and (3) more efficient mechanized harvesting and processing methods in the woods, sawmill, and secondary manufacturing phases.

b. Solving regional problems. Research studies directed toward the solution of specific problems in regional areas vary widely in scope and complexity. Generally, the problems related to specifically assigned research fields, for example, timber characterization and processing, are closely related to the types of research covered in preceding sections 1 to 5 and are reported there, as such studies normally relate to and supplement similar lines of work underway at the Forest Products Laboratory. In some instances, however, relatively short-term studies are carried on in connection with the utilization improvement projects of the Stations in order to provide information needed for the solution of primarily local or regional problems. A few examples include: (1) In the Rocky Mountains, utilization of low-grade ponderosa pine is a serious problem. In New Mexico and Arizona the continuing depressed market for boards has had its greatest impact on the lower Common grades. This has made it especially difficult for the lumber industry because of the higher-than-average yields in the No. 4 and 5 Common grades. A study to determine the alternative conversion that would yield the greatest return showed that the combination of lumber and residue to pulp chips yielded most favorable return. Conversion to all chips was least favorable. The results also showed what grades and sizes of logs are marginal under present harvesting and manufacturing practices. (2) In the Lake States a study on bark removal from pulp chips showed that in dormant-season chipping of fresh wood both chipper type and size of stick affect bark adherence to wood in the chipping action. Bark adhering to chips after the sticks had been through the chipper was reduced from 11.8 percent for the least effective chipper on 2-inch-diameter sticks to 0.2 percent for the most effective chipper on 8-inch-diameter stocks. (3) Studies of felling and bucking Central States upland hardwoods with power chain saws showed that production per man-hour was greater for one-man crews than for two-man crews regardless of saw type (direct- or reduction-drive), size of tree cut, volume cut per acre, or topography of area logged. Also, production per man-hour increased with the size of the trees cut and with the volumes cut per acre. However, production per man-hour was not significantly affected by topography, the type of

saw used, or the species of tree cut. An investigation of logging Central States upland hardwoods resulted in the development of a guide for helping the hardwood logger plan and conduct skidding operation. Another study in the Central States to encourage greater use of hardwoods resulted in the development of wood wall paneling with an attractive "brick and mortar" pattern. The material can be used for paneling walls, facing counters and cabinets, lining clothes closets, and for numerous other applications in the home, office, and public places. Attractive and unusual brick patterns can be obtained by using wood either as a tile or as a strip material. For tile, small thin pieces of wood can be cut to the desired size, beveled on all four edges, and applied to a smooth surface with an adhesive. Or, for a strip material, narrow lengths of wood, with the edges beveled and the surface V-grooved at uniform intervals, can be nailed to studs or other backing. (4) In the Southeast an estimated 2 million dollars is lost annually by treating plants and landowners in the naval stores belt from the practice of "jump-butting" worked-out turpentine timber that is used for making utility poles. A study at the Southeastern Station of pre-treating turpentine longleaf pine poles to improve penetration and retention of creosote showed that bark-hacked, acid-treated, turpentine faces of longleaf pine should meet minimum standards of penetration and retention almost 100 percent of the time if the poles are seasoned to an average moisture content of about 30 percent and then incised and steam conditioned before treating. Prior studies indicated that the wood behind the scar faces of slash pine treats satisfactorily without pretreating. If an inexpensive means of incising only the scar face of these poles is devised, substantial savings to both the treating plants and the landowners should result from the added value of extra pole length when the scar face does not have to be removed. A study of outside storage of hardwood pulp chips in the Southeast, showed major savings from greatly reduced handling costs. Also, the study showed that wood losses during outdoor chip storage are substantially higher in gum species than in oak; however, losses in chip pile storage may be reduced by compaction. Pulp strength losses were confined primarily to loss of tearing resistance, which showed a drop of 10 percent after 90 days storage. Studies of pine and hardwood charcoal as rooting media showed that charcoal mixed with sand significantly increases the percentage of rooted cuttings from some forest tree species. Charcoal rooting media is another outlet for a product from low-quality trees and its use would increase efficiency and profit of nursery operations.

c. Regional research cooperation, activities, and programs. A major function of FUR field effort is to assist and collaborate with established State or regional research agencies to seek a coordinated approach to the solution of regional utilization problems. Also, participation in regional technical and industrial association activities is an important function. In all regions this participation follows a pattern of leadership and technical contributions to groups such as the Forest Products Research Society, Society of American Foresters, and State and regional committees and associations. Another facet involves consulting advice, sometimes assisted by the FPL, to encourage the establishment of industries or to take other action needed to aid in the solution of regional problems. During the past year, this type of contribution has furnished technical information needed for the establishment of: (1) A particle board plant in the Pacific Southwest using sawmill residues, and several plants for the production of lumber from local hardwoods. Assistance has been given over the past several years in connection with the establishment of a major pulp and paper mill. (2) A southern pine plywood industry. Southern Station personnel surveyed available raw material and contacted potential producers as to the program of the FPL designed to develop methods of successful manufacture. (See IV, A-2-e.) Extensive development of the industry is expected this year. (3) The Wood-Use Demonstration Center at Quicksand, Kentucky. The Central States Station continues to be actively involved in its development. Sponsored by the State and partly financed by

the ARA, the purpose of the Center is to stimulate the economy of eastern Kentucky. The Station has been given responsibility for approving project plans and proposed equipment purchases under the ARA grant for the project.

d. Assisting extension and action agencies. The application of research results necessarily must be brought about in many different ways. Station FUR work program emphasizes maximum assistance to the established public extension and action agencies to do this.

Assistance to extension agencies have involved primarily technical advice and guidance and the training of extension workers. Our points of contact are the State Extension Services, the Forest Service Regional Divisions of State and Private Forestry, and the Cooperative Forest Management staffs of the State Foresters. With the assistance of the FPL, backstopping and training has continued actively for these groups.

Help to action agencies has been concentrated mainly on the Rural Area Development (RAD) activities of USDA especially in connection with projects referred by the Area Redevelopment Agency of the Department of Commerce. All Stations have assisted in RAD basic planning and on the details of development programs, pilot economic studies, and investigations and recommendations on specific proposals. Activities vary widely in relation to technical knowledge and experience available from local sources and other agencies.

e. Regional-FPL liaison. The Station FUR Divisions function basically as regional representatives of the Forest Products Laboratory. The performance of this function pays large dividends to the FPL in improved research program quality, balance, and effectiveness; and to the Regions in problem solution, technical backstopping, and economic advances. Liaison activities at the Stations have continued through selecting research material and arranging for its protection and shipment for various FPL studies, enlisting FPL cooperation on interregional problems in which research can contribute to a solution; and informing FPL of significant regional and technical developments related to its program.

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B. FOREST ENGINEERING RESEARCH

Problem

Multiple-use requirements dictate that highly efficient engineering systems be developed to permit protection and maximum utilization of our forest resources under proper management practices. Past research in this field has been largely confined to projects with relatively limited objectives in contrast to the need for coordinated systems required by multiple use considerations. National Forest lands especially pose a challenging problem in utilization and protection due to their relative inaccessibility and land management objectives.

One of the most important forest activities is the harvesting of the timber--a major materials handling and transportation job. Reduction of costs in this activity will be of significant assistance to the timber industry and aid in improving management of forest lands.

Harvesting can be as much as 70 percent of the cost of producing and delivering wood to the primary processing plant. In the case of a pulp plant, the cost of wood at the plant represents 60 percent of the cost of producing unbleached kraft pulp. In other basic industries cost of raw materials in proportion to total production costs runs significantly lower. (For example, in plastics it is only 10 to 30 percent.)

Mechanization, comparable to that achieved in American agriculture is sorely needed. The output per unit of labor in agriculture is nearly double that for forest industries.

Results of a recent study indicate that in Oregon and Washington alone there are at least 28 billion board feet of timber, characterized by low volumes per acre, steep growing terrain and costly road access, which will require special harvesting and removal techniques.

An additional 55,000 miles of access roads are estimated to be required for harvesting the timber cut planned on National Forests alone in the next 10 years. Vastly improved transport and harvesting methods are needed to protect soil and water resources, to harmonize timber harvesting with other multiple-use requirements such as recreation, and to avoid loss of productive growing areas to road rights of way.

In Alaska there are an estimated 61 billion board feet of timber which cannot be successfully logged with the conventional systems that are costly to the operators and damaging to soil, water, and aesthetic values.

Heavy residues of current and past logging in heavy timber stands of the West Coast are wasteful of materials, create an explosive fire hazard, and interfere with re-establishment of the timber resource.

Logging systems and equipment for economical timber harvesting and cultural operations on small woodland ownerships are nearly nonexistent. Specialized equipment is urgently needed.

In eastern hardwoods some 74 percent of the total volume is considered low grade and culls, requiring vastly cheaper harvesting methods so they can be removed economically and the sites replanted to improved species.

Sharply reduced nursery and planting costs are needed to accelerate the job of replanting 52 million acres of commercial forest land--about 11 percent of all commercial forest land.

Program

The possibilities of engineering research in multiple-use forestry operations are being expanded almost daily by the rapid development of new materials and methods of construction, new chemicals, new forms of transport, new forms of energy, and new devices for automatic control. We are experiencing a tremendous explosion in technology and the need now in forestry is to perfect the engineering systems to take advantage of these advances.

Seven major problem areas involved in multiple-use forestry have been selected and plans made to establish engineering laboratories in the geographical area in which each problem is dominant. Most problems are not confined to a single geographic area, consequently, each laboratory will have national, or at least interregional, responsibility for its assigned mission. The research will be primarily applied.

Research in each problem area will concentrate largely on one of the most important of forest engineering activities--materials handling and transportation. Research will begin with an engineering systems analysis. The first step in the analysis will be the preparation of a prescription for the job to be done. It will define the performance goals and the criteria for attainment of the engineering system or process required. The next step will be synthesis, or model building, wherein real systems will be simulated as a means of evaluating alternative forms of operations.

The translation of multiple-use land management requirements and operations into engineering terms and "systems of operations" is a pioneering attempt in both engineering and forestry which requires new approaches and concepts, and much imagination and inventiveness.

The total process can then be divided into subprocesses for further study and design. The final step will be systems development, involving the creation of new types of equipment, improved methods, and new concepts of process organization.

Once the specifications are drawn, a review and appraisal will be made of any and all items of existing equipment believed capable of meeting requirements. If existing equipment cannot meet the specifications, it will be necessary to obtain modifications or to develop prototype new equipment. To the extent possible, private industry will be encouraged to do this work, either independently or by contract. If industry help cannot be obtained, the work may have to be done by the Forest Service.

The prototype or modified equipment will then be tested against the specifications. If necessary, a production model will be obtained and tested against the job to be done.

Close liaison will be maintained with other agencies, both domestic and foreign, engaged in forestry and equipment development and with equipment manufacturing industries, as well as with defense laboratories, to determine whether presently developed equipment, processes, or techniques can be advantageously applied in forestry operations. The program will be directed particularly to original applications designed to revolutionize forest production, protection, and utilization while considering other multiple-use requirements.

Laboratories have been established by assignment of project leaders at Auburn, Alabama (Auburn University); at Houghton, Michigan (Michigan College of Mining and Technology); at Bozeman, Montana (Montana State College); and at Seattle, Washington (University of Washington). Each is closely associated with the engineering college or school where mutually profitable cooperative research programs are planned.

The objective of the work at each laboratory will be to improve the efficiency and economy of forestry systems in its assigned problem area. (Included in the systems are methods of harvesting and transportation, reestablishment of forests, timber stand and watershed protection and improvement, and providing means of access for all multiple use purposes.) The assigned problem areas are:

Bozeman, Montana--Relatively small-sized timber on steep slopes and erodible soils.

Houghton, Michigan--Deteriorated northern hardwood stands located, generally, in rolling terrain.

Auburn, Alabama--Intensively managed timber stands and component forestry operations in seed production and nursery operations.

Seattle, Washington--Virgin timber stands and utilization of heavy residues characterized by West Coast and Alaska forests.

The Federal scientific effort devoted to research in this area totals seven professional man-years.

Progress

The engineering research program of the Forest Service represents a new approach to improving the efficiency and performance of forestry operations. Work to date has been concentrated largely on the development of engineering systems analyses to identify problem areas. Studies contributing to basic understanding of a major problem area, that of materials handling, have progressed as follows:

1. Pipeline Transportation

Earlier studies showed that, hydraulically, transport of large volumes of wood chips in water pipelines was feasible. Current work investigating the engineering economics of such transportation has produced a mathematical model by which various pipeline designs can be evaluated. Costs per ton-mile for movement of bone-dry chips can be determined for pipe diameters from 6 to 20 inches and lengths from 10 to 500 miles. Sixteen variables affecting the cost of pipeline operation have been included.

2. Chipping in the Woods

An analysis of problem areas needing engineering research identified increased woods chipping as a potential for reducing pulp production costs. One study was begun on an integrated harvesting, woods chipping, and transport system to reduce cost of Lake States wood pulp. Two additional studies were begun, one on development of a low-cost favorable horsepower-to-weight ratio power unit, and one on a chipping device requiring low-power inputs.

3. Harvesting Small Wood in Pine Stands

A system was designed using a newly developed low-cost portable skidder to economically harvest small wood (d.b.h. 2 to 6 inches, 40 to 50 feet high). The system appears to offer significant cost savings in clearing land for replanting and for thinning operations. In addition, the small wood can be utilized instead of being disposed of by burning or crushing.

4. Helicopter Logging

A study involving "Factors to be considered in experimental logging with helicopters in the Pacific Northwest and Alaska" was completed following an earlier study on "Some factors affecting the feasibility of helicopter logging in the Pacific Northwest and Alaska."

Work was begun on specialized log pickup and release gear needed for using helicopters in log harvesting operations. Encouraging progress has been made.

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V. FOREST ECONOMICS AND MARKETING RESEARCH

A. FOREST SURVEY

Problem

Up-to-date information on trends in the Nation's forest land and timber resources and on the outlook for timber supplies and demands is essential to guide the policies and programs of forestry agencies and the business policies of forest industries. Information needed includes basic inventory data on the area and condition of forest lands by various classes of ownership; the volume, quality and location of standing timber, trends in timber growth and mortality; and the present and prospective amount and kind of timber cut for industrial products. Because of rapid changes in resources resulting from growth, industrial cutting, and changes in land use there is need for periodic resurveys and analyses of the timber situation for all timber States and for the Nation as a whole. Continued progress and increased efficiency of inventories of the Nation's 775 million acres of forest land also depend on continuous development of improved survey methods and techniques for measuring and classifying forest land and timber, and for compiling and analyzing forest resource data.

Program

This continuing long-range program of applied research is conducted primarily through the field experiment Stations of the Forest Service in close cooperation with State forestry agencies, wood-using industries and other cooperators who contribute manpower and funds. Essentially all of the 775 million acres of forest land in the United States has been inventoried at least once. Resurveys to provide up-to-date information and to determine trends in timber supplies, forestry problems and forest industrial development opportunities are being made in all States at intervals of from 8 to 15 years.

Research on timber inventories and industrial use of timber involve about 66 professional Federal man-years annually.

Progress

a. Progress on forest inventories. During recent years the nationwide Forest Survey has been completing inventories on an average cycle of about 11 years compared with an average goal of somewhat less than 10 years between Surveys. Field surveys have been underway in all sections of the country during the past year, including Alaska, Washington, Oregon, California, New Mexico, Arizona, Minnesota, Illinois, Kentucky, Alabama, Louisiana, North Carolina, and Maryland. Examples of information obtained on forest resources and industries, trends in the forest situation, and forestry problems and opportunities are given in the following items.

b. Tennessee's timber resources increasing. Tennessee has more timber--both pine and hardwood--than it did a decade ago. Total growing stock in sound well-formed trees at least 5 inches in diameter now totals 7 billion cubic feet. Volume of softwood growing stock increased 33 percent and hardwoods gained 22 percent in the 12 years since 1950. Sawtimber volume now totals

20 billion board feet. Softwood sawtimber volume increased 37 percent, hardwood sawtimber 18 percent. Another favorable aspect was a 15 percent gain in hardwoods 18 inches and larger in diameter. Improved fire protection, ingrowth of young trees into sawtimber size, and more widespread timber management are largely responsible for the increases. Commercial forests now occupy 13.4 million of the State's 26.5 million acres. This is about a million acres, or 9 percent more forest land than in 1950, due mainly to reversion of farmlands to forest.

c. Substantial timber inventory in Idaho. Idaho has 21.8 million acres of forest occupying 41 percent of all land. Almost three-fourths of the forest land, or 15.8 million acres, is classed as commercial. About 80 percent of the forest land is managed by Federal agencies, mostly National Forests. Sawtimber volumes still total about 115 billion board feet, one-third of which is Douglas-fir. Net annual growth of sawtimber is about 1.6 billion board feet. The sawtimber cut in 1956 was 1.9 billion board feet, and the annual cut during the period 1947-54 averaged about 1.3 billion. In recent years the cut of western white pine and ponderosa pine has declined, while the cut of Douglas-fir, Engelman spruce, and the true firs has increased appreciably. This trend has increased opportunities for improved forest management.

d. Forest resources of Hawaii surveyed. Hawaii has nearly 2 million acres of forest--almost half the total area of the State. About 1.1 million acres of this land is considered capable of producing industrial wood but most of this is poorly stocked with low quality native forests. Planted stands comprise 2 percent of the area, but contain 23 percent of the sawtimber volume. The planted stands average some 8,000 board feet per acre compared to barely 500 board feet for native stands. Some planted forests show growth rates exceeding 3,000 board feet per acre per year, while most stands have growth ranging from 500 to 1,500 board feet per acre. Because of general land shortage, conversion of forests from watershed protection alone to multiple use for production of water, timber, forage and recreation is of high importance. The harvest of sawtimber, craftwood, and veneer logs in 1960 totalled about one million board feet, compared to annual imports of almost 100 million board feet.

e. Timber harvest declines in northern Minnesota. The number of primary wood-using plants operating in northern Minnesota in 1960 was 10 percent less than in 1952. Lumber production declined about 25 percent, and the cut of fuelwood and mine timbers also dropped sharply. On the other hand, output of pulpwood, veneer logs, poles and piling showed appreciable increases. Overall, the output of timber products in 1960 amounted to 1-1/3 million cords, 15 percent less than in 1952.

f. Record output of Southern pulpwood. The 1961 pulpwood harvest in the South reached an all-time high of 24.2 million cords, or 60 percent of all pulpwood produced in the Nation. The increase of 3 percent over 1960 consisted entirely of hardwood bolts and chipped residues. Chip receipts rose 12 percent of 3.2 million cords. The hardwood cut increased by 400,000 cords to 4.9 million cords, with one-fourth of this gain in the form of chips. Although 70 percent of the hardwood was still from soft-textured species, demand for dense-textured species also has been steadily rising.

In the Central States, pulpwood production continued upward for the seventh consecutive year to more than a half million cords. Pulpwood production in

the Lake States totalled 3,152,000 cords in 1962, or 6 percent less than in 1960.

g. Central States veneer log and cooperage production increasing. Veneer log production in the Central States totalled 59 million board feet in 1960, an increase of 12 percent over 1958. Almost one-third of this was black walnut, having a stumpage value in excess of \$3.7 million. Cooperage log and bolt production in the Central States in 1960 exceeded 120 million board feet, 33 percent higher than 1958 output.

h. Improved procedures for forest inventories developed. Research in survey techniques includes a comprehensive statistical evaluation of procedures for continuous forest inventories with partial replacement of field samples. Results indicate that use of remeasured permanent plots and partial replacement of the initial sample will yield more efficient estimates of current mean volumes of timber than conventional designs. Automatic data processing machine programs recently developed have improved the efficiency of survey compilations and of long-range growth projections such as needed in national appraisals of the timber situation. A new detailed Forest Survey Handbook has been developed to assure greater uniformity of inventory specifications and results among Stations and Regions.

i. Public Law 480 projects. Three Forest Survey research projects conducted by scientists in Finland under sponsorship of the Division of Forest Economics and Marketing Research include:

1. Project No: E8-FS-30

Title: Increment forecast methods for a large forest area.

Objective: To appraise available methods of estimating future forest growth and develop new or improved procedures for forecasting short-term and long-term growth increment and development of growing stock on large forest areas.

2. Project No: E8-FS-32

Title: Improved Forest Survey methods.

Objective: To evaluate alternative designs for forest surveys and determine the relative merits, efficiencies, and costs of each for obtaining forest statistics for local planning and for regional or national appraisals of the forest situation and outlook.

3. Project No: E8-FS-40

Title: Regional comparisons between the actual cuttings, cutting plans, growth, and forest resources. Theory, interpretation and analysis of selected countries.

Objective: A. To systematize, clarify and define the concepts required in national comparisons between actual timber cutting, cutting plans, growth and forest resources. B. To investigate

the influences of national economy on the theory and practice of forest management for private forests and other smaller units of forest. C. To analyze the methods and interpretations of calculations in this field in Finland, Sweden, Norway, USA, and Canada.

All three projects have been underway for more than two years, and will be completed during the coming year.

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B. FOREST ECONOMICS

Problem

Establishing, protecting and managing forest resources involve many alternatives and questions concerning investments, costs and benefits which land-owners and public land managers must resolve. New capital outlays on public and private lands for production of timber, water, recreational services, wildlife and forage are increasing and conflicts between alternative uses of forest land are becoming more frequent.

Administrators of the many million acres of public forest land in the nation require sound criteria and guides to efficiently allocate public funds among alternative practices and producing units, and to integrate multiple uses of forest land for fullest public benefit. Managers of industrial forests must develop management plans based on cost and return determinations in accord with company policies and objectives. Production and investment decisions of $4\frac{1}{2}$ million farmers, businessmen, professional people and other occupational groups also are influenced by economic considerations. Economics analyses are needed to more effectively formulate forest policies and programs, to determine equitable institutional arrangements for forest conservation, and to assure optimum allocation of resources for improving supplies of forest products and services.

Program

The Department conducts a continuing long-term program of applied research, primarily through the field experiment stations of the Forest Service. Close coordination of economics with forest management research is essential in studying problems of timber growing; with forest fire, disease, and insect research and other agencies in appraising problems of forest protection; and with watershed, range and recreation research on problems of competing and multiple uses of forest lands. Cooperation also is maintained

with the Economics Research Service, State Agricultural Experiment Stations and Forestry schools to coordinate related programs. The Federal effort devoted to research in this field totals 26 professional man-years annually.

Progress

a. Planning stand improvement investments on National Forests. Concepts, principles and methods for planning investments in timber stand improvement were developed for work conferences of the Timber Management Division of National Forest Administration. Emphasis was given to determinations of the optimum allocation of public funds for alternative stand treatments and producing units. A handbook for evaluating timber stand improvement projects on the National Forests in terms of prospective costs and benefits is being prepared as an aid to foresters concerned with planning and administering such work.

b. Well-managed forest provides jobs. More than 100,000 workers primarily dependent upon managed forests are now employed in growing and manufacturing timber in Louisiana, Arkansas, east Texas and southeast Oklahoma, or about one-third of the region's manufacturing workers outside the major metropolitan areas. There are about 189 workers per 100,000 acres of commercial forest land, including 11 in forestry operations, 54 in logging, and 124 in manufacturing. With more intensive management, the region's 54,000,000 acres of forest land could support an estimated 414 workers per 100,000 acres, including 16 in forestry, 133 in logging, and 265 in manufacturing.

c. Landowners and industries benefit from tree farm families. In 1961 more than 500 owners in the Mid-south, with nearly 500,000 acres of woodland, had informal cooperative management agreements with forest industries. Half of these owners had woodlands larger than 250 acres; 40 percent had tracts of 50-249 acres and 10 percent had areas less than 50 acres. About 40 percent of the owners were absentee owners. Three-fourths of the owners cited free technical forestry assistance as the main advantage of cooperation, assurance of markets for timber was next in importance. The industries expected cooperating landowners to give them first refusal on stumpage sales.

Cooperative agreements for the most part were informal and unwritten. Further expansion of this type of industrial cooperation and service appears to provide an important way of improving productivity of small woodland ownerships.

d. Woodlands in the urban fringe area of Michigan. Small woodlands in southern Michigan are estimated to be shifting to nonforest uses, primarily urbanization, at the rate of 1.0 percent annually. On the other hand, shifts from agriculture to forest use in recent years have more than offset these losses. Nearly two-thirds of the woodland area is in ownerships having less than 25 acres of forest; 88 percent of the owners have less than 50 acres of woodland. Few owners planned to increase output of forest products and few intended to clear woodland for agriculture.

e. Impact of recreation on timber production. Detailed analyses of three selected National Forests in California indicate that the capacity of recreational developments could be increased to 10 times the present

total capacity, with a maximum reduction in sustained yield capacity for timber at this level of recreational development of about 13 percent. Multiple-use management on the 3.5 million acres in these National Forests could provide about 40 million visitor-days of recreation, plus almost 240 million feet of timber at sustained yield capacity. The sustained yield capacity foregone on recreation land is estimated at about 1.8 cents worth of annual timber yields per visitor-day.

f. Evaluation of watershed treatments in the Southwest. Preliminary studies in the Beaver Creek watershed of Arizona show the following average annual yields in untreated cover types:

<u>Cover type</u>	<u>Water</u> (area inches)	<u>Forage</u> (pounds per acre)	<u>Total herbage</u> (pounds per acre)	<u>Timber</u> (cu.ft. per acre)
Ponderosa pine	4.3	100	190	334
Alligator juniper	3.1	190	450	1-3
Utah juniper	0.4	20	205	2-4

Removal of juniper in the Utah juniper type was found to increase grass forage 2 times and total herbage 2 to 3 times. Similar treatment in the alligator juniper type showed no increase in grass yields and only a small increase in total herbage. Conversion of ponderosa pine type of grass increased forage and total herbage 4 to 5 times. Thinning of pine stands increased grass and herbage yields 2 to 3 times.

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C. FOREST PRODUCTS MARKETING

Problem

Producers of lumber and other wood products have been increasingly faced with serious problems of declining markets and prices, and reduced employment in many forest communities. In a number of areas wood products have been displaced by competitive products either better adapted to the needs of consumers, or available at lower cost. At the same time forest land-owners have frequently received relatively low returns from sales of timber and have had little interest in investing for production of timber crops.

There is need to determine the relative efficiency of alternative marketing systems and practices, including for example the optimum combinations of products obtainable from available timber, and the economic possibilities of new arrangements to overcome the difficulties of small scale forestry operations. Market development studies are needed to determine quantities and locations of economically available species and qualities of standing timber and residues, and the economic feasibility of new or expanded industries based on their use. Strengthened research on wood consumption and trends in timber requirements is needed to better appraise future markets and prospective resource problems, and thus to guide forest policies and programs aimed at keeping the Nation's timber budget in balance.

Program

This is a continuing program of applied research conducted in part by the regional experiment stations and partly by the Washington staff. Close cooperation is maintained with other scientists, particularly with forest products and engineering researchers in coordinating research on mutual problems, and in joint conduct of some studies. Cooperation also is maintained with the Statistical Reporting Service, State Agricultural Experiment Stations, forestry schools, and with various forest products trade associations. Forest owners, loggers, mill operators and wood consumers cooperate by supplying information and by permitting access to active operations for the collection of processing and marketing data.

The Federal effort devoted to research in this area totals 31 professional man-years annually.

Progress

a. Consumption of timber products up in 1962. Continuing studies of the demand and price situation for timber products showed a rise in the consumption of most timber products in 1962 over the low levels of 1960 and 1961. Total consumption of all products was estimated at 12.2 billion cubic feet--some 0.4 billion cubic feet above consumption in 1961 and 0.3 billion cubic feet higher than in 1952. Production from domestic forests amounted to 10.7 billion cubic feet and net imports 1.5 billion cubic feet. The rise in domestic production in 1962 came from increases in the output of sawlogs, pulpwood, and softwood veneer logs.

Lumber consumption in 1962 was estimated at 37.4 billion board feet--some 1.7 billion board feet more than in 1961. Domestic lumber production was 32.9 billion board feet--an increase of 1.1 billion board feet over 1961. Net lumber imports amounted to 4.1 billion board feet and composed 11 percent of consumption.

b. Outlook for naval stores appraised. A comprehensive appraisal of the U. S. naval stores industry indicated that striking changes have occurred in sources of rosin even though total domestic production has increased little since the early 1900's. At that time all rosin was produced from pine gum, compared to 23 percent in 1961. Production of steam-distilled wood rosin from southern pine stumps started about 1910, increased to 70 percent of total production in 1955, then declined to 54 percent in 1961. Commercial production of tall oil rosin from sulphate pulping liquors started in 1949 and has increased to 23 percent of total rosin output in 1961. Substantial further changes are expected in response to future domestic and foreign supply and market conditions. To meet prospective rosin demands in 1970, a projected 34 percent decline in wood rosin output is likely to be more than offset by increases of 75 percent and 65 percent respectively in domestic tall oil rosin and gum rosin production. Results of this study are of major importance to producers and consumers of naval stores throughout the world, and to industrial and forestry agencies concerned with management of southern pine resources.

c. Species competition in eastern lumber markets. A study of approximately 1,000 lumber yards of eastern United States showed that southern pine dominates the sale of common grades of boards in most yards located south of a line extending from Oklahoma to New Jersey. Most of the yards north of this line listed ponderosa pine as the leading species of common boards handled except in a few cities in the prairie states and the Ohio valley where Douglas-fir was the sales leader. In the major market for 2 x 4 studs, southern pine led sales only in areas near the producing mills. Douglas-fir has now taken over the southern market in many industrial areas such as the piedmont of Georgia and Alabama, the New Orleans area, south Florida, and most of Texas. Douglas-fir studs also dominate sales in most northern States. For wider dimension lumber (2 x 6's, 2 x 8's, and other sizes used mainly for joists, rafters, and other construction applications) southern pine dominated sales throughout most of the producing region. Throughout most of the North, Douglas-fir was the principal wide dimension sold.

d. Loose dollars at southern pine sawmills. A study at 29 Alabama sawmills showed that more than 8 percent of the salable volume of logs was lost by cutting lumber thicker and wider than necessary. Additional volumes were lost in trimming lumber to length. Boards sawn too thick or too wide also proved to be more costly to dry, plane, and handle. These losses in the sample mills averaged from \$2 to \$4 per thousand board feet produced--an amount that equalled or exceeded net operating returns in several instances. Major improvements in sawing accuracy can be obtained largely through the application of quality control techniques.

e. Wood use in housing. A continuing analysis of wood products use in residential construction indicates that the lumber content of new single-family homes inspected by the Federal Housing Administration has changed little during the past decade. The amounts of plywood, fiberboard, and other wood materials used per home have, however, increased appreciably. The increase in total wood use during the past 10 years apparently is due mainly to the fact that the size of houses built has been increasing and that more of them have a garage or carport--often a two-car structure rather than the one-car size that predominated in the early 1950's.

The wood content of new, single-family homes, differs greatly among the various regions of the country. Thus in Florida, where masonry exterior wall construction predominates and most houses are built on a concrete slab, lumber use per FHA-inspected house now averages approximately 5,500 board feet. In the South Atlantic region, where approximately 99 percent of the houses have wood frame exterior walls and less than 15 percent are built on a concrete slab, lumber use per house averages more than 12,500 board feet. Similarly, plywood use per house ranges from about 800 square feet in the Southwest to more than 2,100 square feet in the North Atlantic. Fiberboard use averages about 100 square feet per house in Florida, but more than 1,200 square feet in the Lake States.

f. Wood use by manufacturers. A study covering 42,155 sample establishments shows that U. S. manufacturers used approximately 11.6 billion board feet of lumber during 1960--a drop of about 7 percent since 1948. Of the total amount used in 1960, 82 percent went into products made for sale; 13 percent into pallets, boxes, jigs, and patterns made and used by the same establishment; and the remaining 5 percent into dunnage used in shipping. The total volume consumed was about equally divided between softwoods and hardwoods. Nearly two-thirds of it was used for four products--furniture, pallets, containers, and millwork. Manufacturers also used 771 million board feet of bolts in 1960, 4,409 million square feet of veneer, 2,759 million square feet of plywood, 883 million square feet of hardboard, and 155 million square feet of particleboard.

g. Southern pulpwood prices. Continuing studies in the South and Southeast show that the pulpmills of those areas paid a record sum of \$350 million for the pulpwood consumed in 1961. Approximately 85 percent of this amount was for wood delivered as bolts; the remainder was for chips supplied by sawmills and other wood-using industries. Prices paid per cord for pine pulpwood averaged \$15.87 in the Midsouth and \$16.55 in the Southeast--up \$.58 and \$1.05 per cord, respectively, since 1957. Hardwood prices averaged \$13.05 per cord in the Midsouth and \$13.50 in the Southeast, a reduction of \$.30 per cord since 1957 in the Midsouth but an increase of \$.15

per cord in the Southeast. Pulp chip prices averaged about \$6.40 per ton for pine and \$4.96 per ton for hardwood.

h. Pulp and paper making opportunities in west central Colorado. An evaluation of the costs and availability of wood, water, labor, power, transportation, and other items indicates that a good opportunity exists for pulp and paper manufacture near large, growing markets in western Colorado. Timber stands in the area could support an estimated production of at least 600 tons of newsprint daily. Additional wood supplies are available from dead timber and from chippable waste available at sawmills. Wood could be obtained at several likely millsites for a delivered cost of \$20 per cord or less. The Colorado River has enough pulpmill effluent assimilative capacity to sustain 2,000 tons a day of draft, or 360 tons a day of semichemical pulping, or 20,000 tons a day of ground wood pulping distributed among at least four suitable mill locations. Water for pulp and paper manufacture is of acceptable quality with minor treatment. The large and growing paper markets of the area could be served at relatively low freight rates from several possible mill locations.

i. Charcoal production shows rise. A nationwide survey showed that charcoal production amounted to 328,000 tons in 1961, or 24 percent above the 265,000 tons produced in 1956, the previous post-war peak year. Thirteen large producers, each producing more than 5,000 tons of charcoal, accounted for 56 percent of total production. The remaining production came from 284 plants, including 126 that produced less than 100 tons each. The potential annual capacity, i.e., the quantity of charcoal that could have been produced in a 310-day operating year by all manufacturers in 1961, was about 2.5 times actual production. Fifty plants produced 236,000 tons of charcoal briquettes in 1961. Forty-four of these plants with 97 percent of the production were in the East, largely in the Southern, Lake, and Central regions.

j. Timber industry opportunities in West Virginia. Possibilities appear promising for establishment or expansion of wood-using plants in the Beckley-Hinton area of southern West Virginia, according to initial appraisals of timber marketing prospects in West Virginia. The initial report on a series of studies underway appraises various production factors which determine timber market potential in this area. Included are evaluations of timber resources, labor, water, transportation facilities, and financial assistance available for production of lumber, pulp and particle board, and for the flooring and furniture industries. These and additional important factors in various areas of the State are being evaluated in other current timber marketing studies.

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WORK AND LINE PROJECTS, TIMBER MANAGEMENT RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1962 to April 30, 1963

Work and Line Project Number		Work and Line Project Titles		Work Locations	Line Projects Summary Index
CPO	FS				
SILVICULTURE OF EASTERN FOREST TYPES					
FS 1 1-1 (LS)	FS-LS-1101	Site requirements of Lake States forest species		St. Paul, Minnesota Marquette, Michigan Grand Rapids, Minn. East Lansing, Mich. Cadillac, Michigan Ames, Iowa Athens, Ohio Bedford, Indiana Berea, Kentucky Carbondale, Illinois Columbia, Missouri Brewer and Orono, Maine Burlington, Vermont Elkins, W. Virginia Laconia, N. H. Laconia, N. H. New Lisbon, N. J. Warren, Penna. Charlottesville, Va. Asheville, N. C. Durham, N. C. Durham, N. C. Charleston, S. C. Athens, Georgia Macon, Georgia Macon, Georgia Olustee, Florida	I, A-1 I, A-3, A-5-a, B-1 I, A-1, A-2-b, A-5-a I, A-2-a, A-4 I, B-2 I, A-2-a I, A-1 I, A-5-c I, A-1, B-1 I, A-1 I, B-1 I, A-2-b, B-1, C-1 I, A-1 I, A-2-a I, A-1, A-4 I, A-1 I, B-1 I, A-2-a I, A-1, A-2-a, A-2-b, B-1
FS 1 1-2 (LS)	FS-LS-1102	Silviculture of northern hardwoods			
FS 1 1-3 (LS)	FS-LS-1103	Silviculture of northern conifers and aspen			
FS 1 1-4 (LS)	FS-LS-1104	Silviculture of mixed hardwoods			
FS 1 1-5 (LS)	FS-LS-1105	Planting and plantation management of Lake States conifers			
FS 1 1-6 (CS)	FS-CS-1101	Establishment of hardwood plantations			
FS 1 1-7 (CS)	FS-CS-1102	Silviculture of upland hardwoods			
FS 1 1-8 (CS)	FS-CS-1103	Silviculture of high-value hardwoods			
FS 1 1-9 (CS)	FS-CS-1104	Silviculture of mixed mountain hardwood types			
FS 1 1-10 (CS)	FS-CS-1105	Silviculture of bottomland and upland mixed hardwoods			
FS 1 1-11 (CS)	FS-CS-1106	Silviculture of oak-hickory and mixed oak types			
FS 1 1-12 (NE)	FS-NE-1101	Silviculture of spruce-fir and associated hardwoods, and white birch			
FS 1 1-13 (NE)	FS-NE-1102	Planting and seeding of northern hardwoods			
FS 1 1-14 (NE)	FS-NE-1103	Silviculture of northern Appalachian hardwoods			
FS 1 1-15 (NE)	FS-NE-1104	Silviculture of beech-birch-maple type in the Northeast			
FS 1 1-16 (NE)	FS-NE-1105	Silviculture of eastern white pine			
FS 1 1-17 (NE)	FS-NE-1106	Silviculture of Coastal Plain and Piedmont forests of the Northeast			
FS 1 1-19 (NE)	FS-NE-1108	Silviculture of Allegheny hardwoods			
FS 1 1-20 (SE)	FS-SE-1101	Silviculture of shortleaf pine-Virginia pine-upland hardwoods			
FS 1 1-21 (SE)	FS-SE-1102	Silviculture of southern Appalachian hardwoods, and hardwood tree improvement			
FS 1 1-22 (SE)	FS-SE-1103	Silviculture and soils in relation to health and growth of trees			
FS 1 1-23 (SE)	FS-SE-1104	Physiology of flowering and seed production			
FS 1 1-25 (SE)	FS-SE-1106	Silviculture of Coastal Plain timber types			
FS 1 1-26 (SE)	FS-SE-1107	Silviculture of southern Piedmont hardwoods			
FS 1 1-27 (SE)	FS-SE-1108	Silviculture of Piedmont loblolly pine, including plantation management			
FS 1 1-28 (SE)	FS-SE-1109	Southern pine seed research, tree improvement, and nursery practice			
FS 1 1-29 (SE)	FS-SE-1110	Silviculture of longleaf-slash pine type			

WORK AND LINE PROJECTS, TIMBER MANAGEMENT RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1962 to April 30, 1963

Work and Line Project Number		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
		<u>SILVICULTURE OF EASTERN FOREST TYPES (continued)</u>		
FS 1 1-30 (SO)	FS-SO-1102	Artificial regeneration of southern pines	Alexandria, La.	I, A-2-b, D-1
FS 1 1-31 (SO)	FS-SO-1106	Silviculture of southern hardwoods	Stoneville, Miss.	I, A-2-b
FS 1 1-32 (SO)	FS-SO-1107	Silviculture of loblolly-shortleaf pine type of the interior South	Crossett, Ark.	I, A-1
FS 1 1-33 (SO)	FS-SO-1101	Silviculture of the Ozark pine type	Harrison, Ark.	
FS 1 1-34 (SO)	FS-SO-1103	Longleaf pine silviculture, and pine regeneration on sandhills	Marianna, Fla.	
FS 1 1-35 (SO)	FS-SO-1104	Silviculture of tension-zone pine-hardwood types	Nacogdoches, Texas	I, A-2-b
FS 1 1-36 (SO)	FS-SO-1105	Silviculture of Cumberland Plateau pine and hardwood types	Sewannee, Tenn.	
FS 1 1-37 (ITF)	FS-ITF-1101	Silviculture in Puerto Rico and the Virgin Islands	Rio Piedras, P.R.	
FS 1 1-38 (WO)	FS-WO-1101	Nutrition and growth of forest trees	Washington, D.C.	
		<u>SILVICULTURE OF WESTERN FOREST TYPES</u>		
FS 1 2- 1 (NOR)	FS-NOR-1201	Silviculture of coastal forests in Alaska	Juneau, Alaska	
FS 1 2- 2 (NOR)	FS-NOR-1202	Silviculture of interior Alaska forests	Fairbanks, Alaska	
FS 1 2- 3 (PNW)	FS-PNW-1201	Seeding, planting, and nursery practices in the Pacific Northwest	Portland, Oregon	I, B-1
FS 1 2- 4 (PNW)	FS-PNW-1202	Effects of silviculture and species composition on soil	Bend, Oregon	
FS 1 2- 5 (PNW)	FS-PNW-1203	Silviculture of lodgepole and ponderosa pines and interior mixed conifers	Corvallis, Oregon	I, A-5-c, B-1
FS 1 2- 6 (PNW)	FS-PNW-1204	Silviculture of true fir-mountain hemlock and Sitka spruce-western hemlock types	Roseburg, Oregon	I, B-1
FS 1 2- 7 (PNW)	FS-PNW-1205	Silviculture of the mixed sugar pine-Douglas-fir—ponderosa pine type	Roseburg, Oregon	I, A-5-b
FS 1 2- 8 (PNW)	FS-PNW-1206	Brush field reclamation	Olympia, Wash.	I, A-5-a
FS 1 2- 9 (PNW)	FS-PNW-1207	Silviculture of young-growth Douglas-fir and related species	Olympia, Wash.	I, A-6
FS 1 2-10 (PNW)	FS-PNW-1208	Prevention and control of animal damage to forest trees	Corvallis, Oregon	I, A-3, C-1, C-2
FS 1 2-11 (PNW)	FS-PNW-1209	Tree improvement and seed orchard management in the Northwest	Berkeley, Calif.	I, A-5-a
FS 1 2-12 (PSW)	FS-PSW-1201	Silviculture of old-growth Sierra forests	Berkeley, Calif.	I, A-2-b, A-5-c
FS 1 2-13 (PSW)	FS-PSW-1202	Forest seeding and planting		

WORK AND LINE PROJECTS, TIMBER MANAGEMENT RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1962 to April 30, 1963

Work and Line Project Number		Work and Line Project Titles		Work Locations	Line Projects Summary Index
CPO	FS				
<u>SILVICULTURE OF WESTERN FOREST TYPES (continued)</u>					
FS 1 2-14 (PSW)	FS-PSW-1203	Silviculture of redwood and Douglas-fir forests		Klamath, Calif.	I, A-2-b I, C-2 I, C-1, C-2 I, A-1, A-4 I, B-2 I, A-3
FS 1 2-15 (PSW)	FS-PSW-1204	Silviculture of young-growth and planted forests		Redding, Calif.	
FS 1 2-16 (PSW)	FS-PSW-1205	Forest establishment and management in Hawaii		Hilo, Hawaii	
FS 1 2-17 (INT)	FS-INT-1201	Silviculture of western white pine and associated species		Moscow, Idaho	
FS 1 2-18 (INT)	FS-INT-1202	Silviculture of ponderosa pine and interior Douglas-fir		Boise, Idaho	
FS 1 2-19 (INT)	FS-INT-1203	Silviculture of lodgepole pine		Bozeman, Montana	
FS 1 2-20 (INT)	FS-INT-1204	Silviculture of western larch and Engelmann spruce types		Missoula, Montana	
FS 1 2-21 (RM)	FS-RM-1201	Silviculture of spruce-fir and lodgepole pine in the central Rocky Mountains		Ft. Collins, Colo.	
FS 1 2-22 (RM)	FS-RM-1202	Silviculture of mixed conifers of the Southwest and the Rocky Mountain aspen type		Ft. Collins, Colo.	
FS 1 2-23 (RM)	FS-RM-1203	Silviculture of ponderosa pine in the Southwest		Flagstaff, Arizona	I, A-4, A-6 I, A-7
FS 1 2-24 (RM)	FS-RM-1204	Windbreak establishment and management in the central and southern Great Plains		Lincoln, Nebraska	
FS 1 2-25 (RM)	FS-RM-1205	Silviculture of ponderosa pine in the Black Hills		Rapid City, S.D.	I, A-6, B-1 I, A-7
FS 1 2-26 (LS)	FS-LS-1201	Shelterbelt establishment and management including tree improvement aspects		Bottineau, N.D.	
<u>FOREST MENSURATION</u>					
FS 1 3- 1 (PNW)	FS-PNW-1301	Mensuration and related timber management techniques in the Northwest		Portland, Oregon	I, B-2
FS 1 3- 2 (INT)	FS-INT-1301	Mensuration and related timber management techniques in the northern Rocky Mountains		Moscow, Idaho	
FS 1 3- 3 (NE)	FS-NE-1301	Mensuration studies of northeastern conifers and hardwoods		Upper Darby, Penna.	
FS 1 3- 4 (SO)	FS-SO-1301	Mensuration studies of southern pines and hardwoods		Hot Springs, Ark.	
FS 1 3- 5 (RM)	FS-RM-1301	Mensuration and related timber management techniques in the central Rocky Mountains and Southwest		Ft. Collins, Colo.	
FS 1 3- 6 (PSW)	FS-PSW-1301	Mensuration and related timber management techniques in the Pacific Southwest		Berkeley, Calif.	

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CPO	FS			
FS 1 4-1 (PSW)	FS-PSW-1401	<u>FOREST GENETICS</u> Genetics of western conifers Genetics of northern conifers and hardwoods Genetic improvement of conifers and hardwoods in the Northeast Genetics of southern pines and hardwoods Identification, classification, and distribution of forest trees	Berkeley, Calif. Rhinelander, Wis. Chestnut Hill, Pa. Gulfport, Miss. Washington, D. C.	I, C-2
FS 1 4-2 (LS)	FS-LS-1401			I, C-1, C-2, D-3
FS 1 4-3 (NE)	FS-NE-1401			I, C-1
FS 1 4-4 (SO)	FS-SO-1401			
FS 1 4-5 (WO)	FS-WO-1401			
FS 1 5-1 (NE)	FS-NE-1501	<u>TIMBER-RELATED CROPS</u> Maple sap production and related tree improvement Naval stores gum production and related tree improvement	Burlington, Vt. Olustee, Florida	I, D-2 I, C-1, D-1
FS 1 5-2 (SE)	FS-SE-1501			
A7-FS-10		<u>PL 480 PROJECTS</u> Investigations on mycorrhizae-forming fungi with special reference to conifers in India The development of techniques for the vegetative propagation of pine trees by means of needle fascicles Basic studies into the most important factors controlling the quality of natural seed crops of forest trees The role of mycorrhizae in northern forests A study of fertilization failure in controlled breeding of forest trees Pollen dispersal and its significance in silviculture and genetics Investigations of pure culture of mycorrhizal fungi of pine Investigation in rooting and growth induction of short shoots of <u>Pinus radiata</u>	Dehra Dun, India Jerusalem, Israel Helsinki, Finland Helsinki, Finland Helsinki, Finland Helsinki, Finland Warsaw, Poland Santiago, Chile	I, A-2-b I, C-2 I, A-2-a I, A-2-b I, C-2 I, A-2-a I, A-2-b I, C-2
A10-FS-8				
E8-FS-1				
E8-FS-31				
E8-FS-44				
E8-FS-50				
E21-FS-17				
S4-FS-3				

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		WATERSHED MANAGEMENT RESEARCH		
FS 16-1 (NOR)	FS-NOR-1601	Erosion and sedimentation, coastal forests	Juneau, Alaska	II, A-3-b
FS 16-2 (PNW)	FS-PNW-1601	Water yield and erosion - Columbia River	Wenatchee, Washington	II, A-1-c
FS 16-3 (PNW)	FS-PNW-1602	Watershed logging methods and streamflow - western Cascades	Corvallis, Oregon	II, A-2-a
FS 16-4 (PSW)	FS-PSW-1601	Snow management research	Berkeley, California	II, A-1-b
FS 16-5 (PSW)	FS-PSW-1602	Water source hydrology	Berkeley, California	II, A-2-b
FS 16-6 (PSW)	FS-PSW-1603	Water yield - lower conifer	Berkeley, California	II, A-2-a
FS 16-7 (PSW)	FS-PSW-1604	Flood and sediment - Southwest	Glendora, California	II, A-3-d
FS 16-8 (PSW)	FS-PSW-1605	Water yield - Southwest	Glendora, California	II, A-1-c
FS 16-9 (PSW)	FS-PSW-1606	Water yield - Hawaii	Honolulu, Hawaii	II, A-2-a
FS 16-10 (INT)	FS-INT-1601	Snowmelt flood and sediment reduction	Moscow, Idaho	II, A-2-b
FS 16-11 (INT)	FS-INT-1602	Soil stabilization, logging, northern Rockies	Boise, Idaho	II, A-2-a
FS 16-12 (INT)	FS-INT-1603	Watershed rehabilitation and protection - high rangelands	Logan, Utah	II, A-2-b
FS 16-13 (INT)	FS-INT-1604	Channel stabilization	Logan, Utah	II, A-3-b
FS 16-14 (INT)	FS-INT-1605	Water yield improvement - Great Basin & Missouri	Logan, Utah	II, A-1-c
FS 16-15 (INT)	FS-INT-1606	Rain-on-snow flood reduction	Reno, Nevada	II, A-1-a
FS 16-16 (RM)	FS-RM-1601	Alpine snow and avalanche research	Ft. Collins, Colo.	II, A-1-b
FS 16-17 (RM)	FS-RM-1602	Water yield snowpack timber - Rocky Mountains	Ft. Collins, Colo.	II, A-1-c
FS 16-18 (RM)	FS-RM-1603	Water yield, soil stabilization - Big Horn, North Platte	Laramie, Wyoming	II, A-3-b
FS 16-19 (RM)	FS-RM-1604	Watershed rehabilitation - Southwest	Albuquerque, N. M.	II, A-3-d
FS 16-20 (RM)	FS-RM-1605	Riparian and wet sites	Tempe, Arizona	II, A-3-b
FS 16-21 (RM)	FS-RM-1606	Water yield upland areas	Tempe, Arizona	II, A-1-c
FS 16-22 (LS)	FS-LS-1601	Runoff and erosion reduction - nonglaciated	La Crosse, Wisconsin	II, A-2-a
FS 16-23 (LS)	FS-LS-1602	Bog and swamp hydrology	Grand Rapids, Minnesota	II, A-3-a
FS 16-24 (LS)	FS-LS-1603	Ground water hydrology and streambank erosion	Cadillac, Michigan	II, A-4-a
FS 16-25 (CS)	FS-CS-1601	Strip mined area restoration	Berea, Kentucky	II, A-1-b
FS 16-26 (CS)	FS-CS-1602	Management of storm runoff	Columbus, Ohio	II, A-3-c
FS 16-27 (NE)	FS-NE-1601	Water yield improvement - New England	Laconia, N. H.	
FS 16-28 (NE)	FS-NE-1602	Floods, erosion and water yield - central Appalachians	Parsons, West Virginia	II, A-1-c

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FS 16-29 (NE) FS 16-30 (NE)	FS-NE-1603 FS-NE-1604	Municipal watersheds Stream regimen and water yields - Northeast	New Lisbon, N. J. Syracuse, N. Y.	II, A-1-c II, A-1-b II, A-2-a II, A-1-c
FS 16-31 (SE) FS 16-32 (SE) FS 16-33 (SE) FS 16-34 (SO) FS 16-35 (SO) FS 16-36 (SO) FS 16-37 (SO)	FS-SE-1601 FS-SE-1602 FS-SE-1603 FS-SO-1601 FS-SO-1602 FS-SO-1603 FS-SO-1604 A10-FS-9	WATERSHED MANAGEMENT RESEARCH Water yield improvement, mountains - Piedmont Wetland improvement Inactive Water timing - Ozark-Ouachita Coastal Plain hydrology - South Watershed rehabilitation - Coastal Plain Management of erosive watersheds Monographic revision of the genus <u>Tamarix</u>	Franklin, N. C. Charleston, S. C. Asheville, N. C. Harrison, Ark. Oxford, Mississippi Oxford, Mississippi Oxford, Mississippi Israel	Inactive II, A-2-a II, A-3-a II, A-3-a New project II, A-5-a

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FS 19-1 (FSW) FS 19-2 (LS) FS 19-3 (LS) FS 19-4 (CS) FS 19-5 (NE) FS 19-6 (NE) FS 19-7 (WO) FS 19-8 (INT) FS 19-9 (INT) FS 19-11 (FNM) FS 19-13 (SE) FS 19-15 (RM)	FS-PSW-1901 FS-LS-1901 FS-LS-1902 FS-CS-1901 FS-NE-1901 FS-NE-1902 FS-WO-1901 FS-INT-1901 FS-INT-1902 FS-FNM-1901 FS-SE-1901 FS-RM-1901	<p>FOREST RECREATION RESEARCH</p> <p>Recreation use - California</p> <p>Recreation - LS</p> <p>Lake States - Univ. of Michigan coop. recreation unit</p> <p>Small woodland recreation</p> <p>Recreation research in the Northeast</p> <p>Syracuse recreation project</p> <p>Forest recreation use</p> <p>Recreation planning and management - INT</p> <p>Forest recreation research unit in coop. with Utah State Univ.</p> <p>Wilderness recreation dynamics</p> <p>Forest recreation management</p> <p>Forest recreation research Rocky Mountains</p>	<p>Berkeley, California</p> <p>St. Paul, Minnesota</p> <p>Ann Arbor, Michigan</p> <p>Columbus, Ohio</p> <p>Upper Darby, Pa.</p> <p>Syracuse, New York</p> <p>Washington, D. C.</p> <p>Ogden, Utah</p> <p>Logan, Utah</p> <p>Portland, Oregon</p> <p>Asheville, North Carolina</p> <p>Ft. Collins, Colorado</p>	<p>II, B-1,2</p> <p>II, B-2</p> <p>--</p> <p>II, B-2</p> <p>II, B-2</p> <p>II, B-2</p> <p>II, B-2</p> <p>II, B-1</p> <p>--</p> <p>II, B-2</p> <p>II, B-2</p> <p>II, B-2</p>

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RANGE MANAGEMENT RESEARCH							
FS 17-1 (PNW)	FS-PNW-1701	Range ecology and management		LaGrande, Oregon		II, C- 2a, 2b, 2c, 3a	
FS 17-3 (PSW)	FS-PSW-1701	Woodland and chaparral conversion and management		Berkeley, California		II, C- 2b, 3b	
FS 17-4 (PSW)	FS-PSW-1702	Management of annual plant and related range		Fresno, California		II, C- 2c	
FS 17-5 (PSW)	FS-PSW-1703	Management bunchgrass ranges		Susanville, California		II, C- 3a, 4	
FS 17-7 (INT)	FS-INT-1701	Sagebrush, cheatgrass and granitic soil ranges		Boise, Idaho			
FS 17-8 (INT)	FS-INT-1702	Northern Rocky Mountain grasslands		Bozeman, Montana			
FS 17-9 (INT)	FS-INT-1703	Salt-desert-shrub, sagebrush-grass, and pinyon-juniper ranges		Provo, Utah		II, C- 1a, 2c, 3a, 3b	
FS 17-10 (INT)	FS-INT-1704	Management of mountain herbland, brushland and aspen ranges		Logan, Utah		II, C- 3b	
FS 17-11 (RM)	FS-RM-1701	Mountain ranges-central Rockies		Ft. Collins, Colorado		II, C- 3a, 3b, 5	
FS 17-12 (RM)	FS-RM-1702	Range biometry		Ft. Collins, Colorado			
FS 17-13 (RM)	FS-RM-1703	Alpine and subalpine ranges		Laramie, Wyoming		II, C- 1a, 2c, 3a	
FS 17-14 (RM)	FS-RM-1704	Southwestern seeded ranges		Albuquerque, N. Mexico		II, C- 3b	
FS 17-15 (RM)	FS-RM-1705	Southwestern chaparral, woodland and forest ranges		Tempe, Arizona		II, C- 1a, 4	
FS 17-16 (RM)	FS-RM-1706	Semidesert cattle ranges		Tucson, Arizona		II, C- 1a, 2a, 2b, 2c, 3a	
FS 17-17 (CS)	FS-CS-1701	Range evaluation and management		Columbia, Missouri		II, C- 1a	
FS 17-18 (SE)	FS-SE-1701	Integrated range-timber wildlife management		Ft. Myers, Florida		II, C- 3b, 4	
FS 17-19 (SO)	FS-SO-1701	Southern pine cattle ranges		Alexandria, Louisiana		II, C- 3a, 4	
FS 17-20 (WO)	FS-WO-1701	Range plant taxonomy		Washington, D.C.			
FS 17-21 (WO)	FS-WO-1702	Range inventory and evaluation		Washington, D.C.			
A10-FS-6	(PL-480)	Germination of seeds of desert plants		Israel			
E25-FS-1	(PL-480)	Studies of botany, ecology, and biology of the principal species in mountain pastures of semiarid regions		Spain			
WILDLIFE HABITAT RESEARCH							
FS 18-1 (PNW)	FS-PNW-1801	Big game habitat--Pacific Northwest		LaGrande, Oregon		II, D- 1, 2	
FS 18-3 (PSW)	FS-PSW-1801	Deer Habitat--California		Berkeley, California		II, D- 1	
FS 18-4 (INT)	FS-INT-1801	Deer winter range--Idaho		Boise, Idaho		II, D- 1, II, C-1a, 5	
FS 18-5 (INT)	FS-INT-1802	Northern Rockies forest wildlife habitat		Missoula, Montana		II, C- 1b	
FS 18-6 (INT)	FS-INT-1803	Game range restoration, and wildlife-livestock relations		Provo, Utah		II, D- 1, 2	
FS 18-7 (RM)	FS-RM-1801	Forest game and fish habitat--Central Rockies		Ft. Collins, Colorado			
FS 18-8 (RM)	FS-RM-1802	Wildlife habitat--Southwestern vegetation types		Tempe, Arizona		II, D - 2	
FS 18-9 (RM)	FS-RM-1803	Wildlife Habitat--Black Hills		Rapid City, South Dakota		II, D- 1	
FS 18-11 (LS)	FS-LS-1801	Conifer-aspen wildlife habitat, Lake States		St. Paul, Minnesota		II, D- 2	
FS 18-13 (NE)	FS-NE-1801	Wildlife habitat in northeastern forests		Warren, Pa.			
FS 18-15 (SE)	FS-SE-1801	Forest wildlife habitat in the Southeast		Asheville, N. C.		II, D- 1, 2	
FS 18-16 (SO)	FS-SO-1801	Wildlife Habitat in southern forests		Nacogdoches, Texas		II, D- 1, 2	

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FS 2 1-1(NOR)	FOREST FIRE		
FS 2 1-2(PNW)	Fire Control Systems	Fairbanks, Alaska	--
FS 2 1-3(PNW)	Fire Control and Use	Portland, Oregon	III, A-1c
FS 2 1-4(PNW)	Fire Weather	Portland, Oregon	--
FS 2 1-5(PNW)	Conflagration Control	Berkeley, California	III, A-4b
FS 2 1-6(PNW)	Fire Control Systems	Berkeley, California	--
FS 2 1-7(PNW)	Fire Chemistry	Berkeley, California	--
FS 2 1-8(PNW)	Fuel Break	Riverside, California	III, A-2c
FS 2 1-9(PNW)	Fire Prevention	Riverside, California	III, A-2a
FS 2 1-10(PNW)	Improvement of Fire Control Methods	Riverside, California	III, A-3c
FS 2 1-11(PNW)	Fire Behavior	Riverside, California	III, A-3c
FS 2 1-12(INT)	(Project to come in later)	--	--
FS 2 1-13(INT)	Project Skyfire	Missoula, Montana	III, A-2b
FS 2 1-14(INT)	Fire Control Systems	Missoula, Montana	III, A-3a
FS 2 1-15(INT)	Fire Physics	Missoula, Montana	III, A-1b, 1c
FS 2 1-16(RM)	Fire Behavior	Missoula, Montana	III, A-1b, 3b
FS 2 1-17(RM)	Fire Control	Fort Collins, Colorado	--
FS 2 1-18(1S)	Fire Use	Flagstaff, Arizona	III, A-4a, 4b
FS 2 1-19(NE)	Fire Control Systems	St. Paul, Minnesota	--
FS 2 1-20(SE)	Fire Control Planning	Upper Darby, Pennsylvania	III, A-3b
FS 2 1-21(SE)	Fire Use	Macon, Georgia	III, A-4a
FS 2 1-22(SE)	Fire Control	Macon, Georgia	III, A-3c
FS 2 1-23(SE)	Fire Potential	Macon, Georgia	III, A-1c
FS 2 1-24(SE)	Fire Environment	Macon, Georgia	III, A-1a
FS 2 1-25(CS)	Fire Models	Macon, Georgia	III, A-1a
FS 2 1-26(SO)	Hardwood Fire Control	Salem, Missouri	III, A-1c
FS 2 1-27(SO)	Fuels and Fire Control	Alexandria, Louisiana	--
FS 2 1-28(WO)	Fire Prevention	Alexandria, Louisiana	--
FS 2 1-29(WO)	National Fire Danger Rating	Asheville, N. C.	III, A-3b
FS 2 1-30(WO)	PL 480--Open Fires and Transport of Firebrands	Madrid, Spain	III, A-1a
FS 2 1-31(WO)			
FS 2 1-32(WO)			
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CPO	FS			
FOREST INSECTS				
FS 2 2-1(NOR)	FS-NOR-2201	Forest Insects, Coastal Forests	Juneau, Alaska	:III, B-4-b, 4-c
FS 2 2-3(PMW)	FS-PMW-2201	Bark beetles, sucking insects, cone and seed insects, wood products insects.	Portland, Oregon	:III, B-1-a, 1-d, 4-a and 4-d
FS 2 2-4(PMW)	FS-PMW-2202	Defoliating Insects, Regeneration Insects, Range Insects.	Portland, Oregon	:III, B-1-d, 2-b, 4-b and 6-b
FS 2 2-5(PMW)	FS-PMW-2203	Diseases of western forest insects.	Corvallis, Oregon	:III, B-1-c, 1-d
FS 2 2-6(PMW)	FS-PMW-2204	Physiology and biochemistry of western forest insects.	Corvallis, Oregon	:III, B-4-b
FS 2 2-7(PMW)	FS-PMW-2205	Biological control of Western forest insects.	Corvallis, Oregon	:III, B-1-a
FS 2 2-8(PSW)	FS-PSW-2201	Toxicology, physiology, and host resistance of forest insects in California.	Berkeley, California	:III, B-1-e, 2-c
FS 2 2-9(PSW)	FS-PSW-2202	Biology, ecology and control of forest insects in California.	Berkeley, California	:III, B-2-c, 3-a, 4-c and 6-b
FS 2 2-11(RM)	FS-RM-2201	Forest insects in the Central Rocky Mountains and Southern Great Plains.	Ft. Collins, Colorado	:III, B-1-a, 2-c, 4-a and 4-b
FS 2 2-12(RM)	FS-RM-2202	Bark beetles and defoliating insects affecting forest trees in the Southwest.	Albuquerque, New Mexico	:III, B-1-c
FS 2 2-13(INT)	FS-INT-2201	Biology, ecology and control of bark beetles, defoliators, and range browse insects.	Ogden, Utah	:
FS 2 2-14(INT)	FS-INT-2202	Biology, ecology, and control of bark beetles	Missoula, Montana	:III, B-4-a
FS 2 2-15(INT)	FS-INT-2203	Biology, ecology and control of defoliators and regeneration insects.	Ogden, Utah	:III, B-1-a

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FS 2 2-16(IS)	Seed and Cone, Aspen, and Shelterbelt Insects	St. Paul, Minn.	:III,B-4-c
FS 2 2-17(IS)	Defoliators	St. Paul, Minn.	:III,B-3-b
FS 2 2-18(IS)	Plantation Insects	East Lansing, Michigan	:III,B-1-a,4-d.
FS 2 2-19(CS)	Forest and plantation insects.	Delaware, Ohio	:
FS 2 2-20(CS)	Physiology and toxicology of insect pests of forest and shade trees	Delaware, Ohio	:III,B-1-e
FS 2 2-21(CS)	Biological control and disease vectors	Delaware, Ohio	:III,B-1-e
FS 2 2-22(NE)	Insect Biology	New Haven, Conn.	:III,B-1-d
FS 2 2-23(NE)	Biotic Control	New Haven, Conn.	:III,B-1-d
FS 2 2-24(NE)	Insect control using synthetic chemicals	New Haven, Conn.	:
FS 2 2-25(SE)	Bark beetles, defoliators, and sucking insects	Asheville, N. C.	:III,B-1-a,4-b
FS 2 2-26(SE)	Insect physiology	Durham, N. C.	:III,B-4-a
FS 2 2-27(SE)	Insects of slash pine seed, plantations and naval stores.	Olustee, Fla.	:III,B-1-d
FS 2 2-28(SE)	Hardwood borers and pine insects	Athens, Georgia	:III,B-1-e
FS 2 2-30(SO)	Hardwood insects, SO	Stoneville, Miss.	:III,B-1-b, 2-a,
FS 2 2-31(SO)	Pine insects, SO	Alexandria, La.	: 2-c, and 4-a
FS 2 2-32(SO)	Wood products insects, SO	Gulfport, Miss.	:III,B-1-d, 5-a, and 5-b.
			:III,B-2-a.

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FS 2 2-33(WO)	FS-WO-2201		
FS 2 2-34(WO)	FS-WO-2202		
FS 2 2-35(WO)	FS-WO-2203		
FS 3 2-10(FPL)	FS-FPL-3210		
	FOREST INSECTS		
	Aerial survey research - eastern U.S.	Beltsville, Md.	III, B-6-a
	Aerial Application Research	Beltsville, Md.	
	Toxicology, Pathology, and Physiology of Forest Insects	Beltsville, Md.	III, B-1-e, 2-c
	Wood Fungus and insects effects and control	Madison, Wisconsin	III, B-5-b
	P.L. 480 PROJECTS		
A7-FS-6	Accelerated Laboratory Investigations on Termite Resistance of Woods.	Dehra Dun, India	
A7-FS-7	Survey for natural enemies of <u>Chermes</u> spp. attacking silver fir and spruce in the Himalayas.	Bangalore, India	III, B-1-a
A7-FS-8	Survey of parasites for gypsy moth.	Bangalore, India	III, B-1-a
A7-FS-25	Survey for natural enemies of <u>Hypsipyla</u> spp. in India.	Bangalore, India	
AL7-FS-1	Survey of Insect Fauna of the Forests of Pakistan.	Peshawar, West Pakistan	
AL7-FS-5	Investigations on the predators of <u>Adelges</u> (an aphid on fir).	Rawalpindi, Pakistan	III, B-1-a
AL7-FS-6	Studies on the natural enemies of insect pests of West Pakistan forests.	Rawalpindi, Pakistan	III, B-1-a
E8- FS-38	Orienting stimuli guiding insect pests of forests to suitable host trees.	Helsinki, Finland	III, B-1-e

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	P.L. 480 PROJECTS		
E21-FS-2	Insects noxious to young stands of pine.	Warsaw, Poland	III, B-1-a
E21-FS-3	Research on the Growth and Development and Disease Susceptibility of some Species of Trees from the U.S.A. to be planted in certain Climatic Regions of Poland.	Warsaw, Poland	
E21-FS-6	Investigations into the activity of the parasite, <i>Trichogramma embryophagum</i> (Hart) introduced into the forest environment with special attention to its capacity for spreading.	Poznan, Poland	
E21-FS-7	Studies in the Development of Improved Strains of Parasites of Forest Insects.	Poznan, Poland	III, B-1-a
E25-FS-3	Pests of poplars and preventive and curative methods of control.	Madrid, Spain	III, B-4-a
E25-FS-10	The study of parasites, predators and diseases of the Gypsy Moth and the possibility of their application in the biological control.	Madrid, Spain	III, B-1-a
S3-FS-7	Disease and insect susceptibility and species adaptability of some North American pine species planted in Sao Paulo.	Sao Paulo, Brazil	
S5-FS-1	Disease and insect susceptibility and species adaptability of some North American forest tree species planted in Colombia.	Medellin, Colombia	

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FOREST DISEASE				
FS 2 3-1 (PMW)	FS-PMW-2301	Forest Disease Control in NW	Portland, Oregon	III C, 3-f
FS 2 3-2 (PMW)	FS-PMW-2302	Soil Microbiology	Corvallis, Oregon	III C, 1-b
FS 2 3-3 (PMW)	FS-PMW-2303	Root Diseases	Portland, Oregon	III C, 2-b
FS 2 3-4 (PMW)	FS-PMW-2304	Planting, Pastures, People, & Products	Corvallis, Oregon	III C, 6-a, 6-c
FS 2 3-5 (PSW)	FS-PSW-2301	Heartrots, Mistletoes, and White Pine Blister Rust	Berkeley, California	III C, 3-b, 3-e
FS 2 3-6 (PSW)	FS-PSW-2302	Diseases of Seed, Seedlings, Reproduction, and Physiogenic Diseases	Berkeley, California	III C, 1-b, 4-f
FS 2 3-7 (INT)	FS-INT-2301	Native Rusts of Western Conifers	Logan, Utah	III C, 3-a
FS 2 3-8 (INT)	FS-INT-2302	Breeding Western White Pine Resistant to Blister Rust	Moscow, Idaho	III C, 3-b
FS 2 3-9 (INT)	FS-INT-2303	Diseases of Western White Pine and Antibiotic Action	Moscow, Idaho	III C, 3-a, 3-e 3-f, 4-a 4-g, 5-b
FS 2 3-10 (RM)	FS-RM-2301	Diseases of Forest Trees and Woody Plants in Central Rocky Mountains and Great Plains	Fort Collins, Colorado Lincoln, Nebraska	III C, 1-a, 1-b 3-a, 3-e 4-g, 5-c
FS 2 3-11 (RM)	FS-RM-2302	Diseases of Southwest Ponderosa Pine and Associated Species	Albuquerque, New Mexico	III C, 2-c, 3-d
FS 2 3-12 (LS)	FS-LS-2301	Diseases of Northern Conifers and Shelterbelts	St. Paul, Minnesota	III C, 3-b, 3-d
FS 2 3-13 (LS)	FS-LS-2302	Diseases of Aspen	St. Paul, Minnesota	III C, 3-d
FS 2 3-14 (LS)	FS-LS-2303	Diseases of Northern Hardwoods	Marquette, Michigan	III C, 1-d, 3-f 5-c
FS 2 3-15 (CS)	FS-CS-2301	Parasitic Diseases and Heartrots	Delaware, Ohio Columbia, Missouri	III C, 2-a, 5-a
FS 2 3-16 (CS)	FS-CS-2302	Physiogenic Diseases	Delaware, Ohio	III C, 4-e
FS 2 3-17 (NE)	FS-NE-2301	Mid-Atlantic Tree Diseases	Upper Darby, Pa.	---
FS 2 3-18 (NE)	FS-NE-2302	New England Tree Diseases	New Haven, Connecticut Iaconia, New Hampshire	III C, 3-f, 6-b
FS 2 3-19 (SE)	FS-SE-2301	Appalachian Hardwood Diseases	Asheville, N. C.	III C, 3-b
FS 2 3-20 (SE)	FS-SE-2302	Annosus Root Rot and Littleleaf	Research Triangle, N. C. Asheville, N. C.	III C, 2-a
FS 2 3-21 (SE)	FS-SE-2303	Rust and Nursery Diseases	Athens, Georgia Athens, Georgia Macon, Georgia	III C, 1-b, 1-c 3-c, 3-d 4-g

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CPO	FS				
FOREST DISEASE					
FS 2 3-22 (SE)	FS-SE-2304	Soil Borne Organisms		Research Triangle, N. C. Asheville, N. C. New Orleans, Louisiana Stoneville, Mississippi Gulfport, Mississippi	III C, 2-d
FS 2 3-23 (SE)	FS-SE-2305	Air Pollution			III C, 4-c, 4-d
FS 2 3-24 (SO)	FS-SO-2301	Wood Decay			III C, 6-c
FS 2 3-26 (SO)	FS-SO-2302	Bottom Land Hardwood Diseases			III C, 3-d
FS 2 3-25 (SO)	FS-SO-2303	Southern Pine Diseases			III C, 2-a, 3-c
FS 2 3-27 (WO)	FS-WO-2301	Cultural Characteristics of Forest Fungi		Laurel, Maryland	III C, 6-f
FS 3 2-10 (FPL)	FS-FPL-3210	Wood Fungus and Insect Effects and Control		Madison, Wisconsin	III C, 6-b to 6-f
P.L. 480					
A6-FS-3		Important Epidemic Diseases of Forest Trees in Taiwan		Taipei, Taiwan	--
A7-FS-5		Accelerated Laboratory Investigations of Durability of Wood		Dehra Dun, India	III C, 6-d
E15-FS-5		Biology and Epidemiology of Pine Twist Rust		Florence, Italy	III C, 4-g
E21-FS-3		Disease Susceptibility of Some North American Tree Species in Poland		Warsaw, Poland	III C, 1-e
E21-FS-16		Saprophytic and Phytopathogenic Fungi and Their Relations in Forest Soils		Poznan, Poland	III C, 2-a
E25-FS-5		Diseases of Native Fir, Pine, and Introduced Pinus radiata acclimatized in Spain		Madrid, Spain	III C, 4-g
S3-FS-7		Disease Susceptibility of Some North American Tree Species in Sao Paulo		Sao Paulo, Brazil	III C, 1-e
S5-FS-1		Disease Susceptibility of Some North American Tree Species in Colombia		Medellin, Colombia	III C, 1-e
S9-FS-1		Disease Susceptibility of Some North American Tree Species in Uruguay		Montevideo, Uruguay	III C, 1-e

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CPO	FS			
FS 3 1-1 (FPL)	FS-FPL-3101	WOOD QUALITY RESEARCH Wood structure and identification Fine wood structure Wood structure-wood property relations Environmental, growth, and silvicultural effects Wood quality evaluation and genetic effects Grading criteria Lumber quality-yield development Sawmill improvement Douglas-fir (and associated species) log and tree grades Western pine (and associated species) log and tree grades Hardwood log and tree grades Northern softwoods log and tree grades Southern softwood log and tree grades	Madison, Wisconsin	--
FS 3 1-2 (FPL)	FS-FPL-3102		Madison, Wisconsin	IV, A-1-a
FS 3 1-3 (FPL)	FS-FPL-3103		Madison, Wisconsin	IV, A-1-b
FS 3 1-4 (FPL)	FS-FPL-3104		Madison, Wisconsin	IV, A-1-c
FS 3 1-5 (FPL)	FS-FPL-3105		Madison, Wisconsin and Asheville, N. C.	IV, A-1-d
FS 3 1-6 (FPL)	FS-FPL-3106		Madison, Wisconsin	IV, A-1-e
FS 3 1-7 (FPL)	FS-FPL-3107		Madison, Wisconsin, Athens, Georgia, and Upper Darby, Pa.	IV, A-1-f
FS 3 1-8 (FPL)	FS-FPL-3108		Madison, Wisconsin, Fort Collins, Colo., and Athens, Georgia	IV, A-2-j
FS 3 1-9 (PNW)	FS-PNW-3101		Portland, Oregon	IV, A-1-e
FS 3 1-10 (PSW)	FS-PSW-3101		Berkeley, California	IV, A-1-e
FS 3 1-11 (CS)	FS-CS-3101	SOLID WOOD PRODUCTS RESEARCH Machining and veneer cutting Product and process development Wood drying Glues and gluing processes Glued wood products Wood finishing Fire performance of wood Environmental effects Preservative development and treating processes Wood fungus and insects effects and control	Columbus, Ohio	--
FS 3 1-12 (NE)	FS-NE-3101		Upper Darby, Pa.	IV, A-1-e
FS 3 1-13 (SE)	FS-SE-3101		Asheville, N. Carolina	IV, A-1-e
FS 3 2-1 (FPL)	FS-FPL-3201		Madison, Wisconsin	IV, A-2-a
FS 3 2-2 (FPL)	FS-FPL-3202		Madison, Wisconsin and Fort Collins, Colo.	IV, A-2-b
FS 3 2-3 (FPL)	FS-FPL-3203		Madison, Wisconsin, Portland, Oregon, Fort Collins, Colo., Athens, Georgia, and Rio Piedras, P. R.	IV, A-2-c
FS 3 2-4 (FPL)	FS-FPL-3204		Madison, Wisconsin	IV, A-2-d
FS 3 2-5 (FPL)	FS-FPL-3205		Madison, Wisconsin	IV, A-2-e
FS 3 2-6 (FPL)	FS-FPL-3206		Madison, Wisconsin	IV, A-2-f
FS 3 2-7 (FPL)	FS-FPL-3207		Madison, Wisconsin	IV, A-2-g
FS 3 2-8 (FPL)	FS-FPL-3208		Madison, Wisconsin	IV, A-2-h
FS 3 2-9 (FPL)	FS-FPL-3209		Madison, Wisconsin, Portland, Oregon, and New Orleans, La.	IV, A-2-i
FS 3 2-10 (FPL)	FS-FPL-3210		Madison, Wisconsin	III, B-5-b, C-6-b to C-6-f

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Work and Line Project Number		Work and Line Project Titles		Line Projects Summary Index	
CPO		FS		Work Locations	
FS 3 3-1 (FPL)		FS-FPL-3301		WOOD FIBER PRODUCTS RESEARCH	
FS 3 3-2 (FPL)		FS-FPL-3302		Pulping process investigations	
FS 3 3-3 (FPL)		FS-FPL-3303		Pulp properties	
FS 3 3-4 (FPL)		FS-FPL-3304		Fiber processing	
FS 3 3-5 (FPL)		FS-FPL-3305		Papermaking processes	
				Converted paper products	
				WOOD CHEMISTRY RESEARCH	
FS 3 4-1 (FPL)		FS-FPL-3401		Wood carbohydrates and conversion products	
FS 3 4-2 (FPL)		FS-FPL-3402		Lignin structure and utilization	
FS 3 4-3 (FPL)		FS-FPL-3403		Chemistry of wood and bark extractions	
FS 3 4-4 (FPL)		FS-FPL-3404		Biochemistry of wood constituents	
FS 3 4-5 (FPL)		FS-FPL-3405		Surface and polymer chemistry of wood	
FS 3 4-6 (FPL)		FS-FPL-3406		Process development	
FS 3 4-7 (FPL)		FS-FPL-3407		Analytical development, instrumentation, and service	
				WOOD ENGINEERING RESEARCH	
FS 3 5-1 (FPL)		FS-FPL-3501		Fundamental wood properties	
FS 3 5-2 (FPL)		FS-FPL-3502		Properties of wood-base and related materials	
FS 3 5-3 (FPL)		FS-FPL-3503		Analytical mechanics	
FS 3 5-4 (FPL)		FS-FPL-3504		Research equipment and method development	
FS 3 5-5 (FPL)		FS-FPL-3505		Design criteria	
FS 3 5-6 (FPL)		FS-FPL-3506		Structural utilization	
FS 3 5-7 (FPL)		FS-FPL-3507		Packaging	
				REGIONAL UTILIZATION PROBLEMS	
FS 3 6-1 (SE)		FS-SE-3601		Utilization improvement, SE	
FS 3 6-2 (SE)		FS-SE-3602		Characterization of southern hardwoods and associated species	
FS 3 6-3 (SE)		FS-SE-3603		Southern hardwood utilization	
FS 3 6-4 (CS)		FS-CS-3601		Utilization improvement, CS	
FS 3 6-5 (CS)		FS-CS-3602		Using Central States timber	
FS 3 6-6 (NE)		FS-NE-3601		Utilization improvement, NE	
FS 3 6-7 (ITF)		FS-ITF-3601		Timber utilization, Tropics	
FS 3 6-8 (LS)		FS-LS-3601		Timber characterization and processing	

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Madison, Wisconsin
Madison, Wisconsin
Madison, Wisconsin
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CPO	FS				
FS 3 6-9 (LS)	FS-LS-3602	Utilization improvement, LS	FOREST ENGINEERING RESEARCH	St. Paul, Minnesota Portland, Oregon Berkeley, California Ogden, Utah Fort Collins, Colorado New Orleans, Louisiana	IV, A-4-f, A-6 IV, A-1-e, A-2-C, A-2-i, A-5-a, A-6 IV, A-1-e, A-6 IV, A-6 IV, A-2-b, A-2-C, A-2-j, A-6 IV, A-2-i, A-6
FS 3 6-11 (PNW)	FS-PNW-3601	Utilization improvement, PNW			
FS 3 6-13 (PSW)	FS-PSW-3601	Utilization improvement, PSW			
FS 3 6-15 (INT)	FS-INT-3601	Utilization improvement, INT and Northern Region			
FS 3 6-17 (RM)	FS-RM-3601	Utilization improvement, RM			
FS 3 6-19 (SO)	FS-SO-3601	Utilization improvement, SO			
FS 3 7-1 (INT)	FS-INT-3701	Engineering systems for steep mountain forestry	P.L. 480 PROJECTS	Bozeman, Montana Houghton, Michigan Auburn, Alabama Seattle, Washington	IV, B-1 IV, B-2 IV, B-3 IV, B-4
FS 3 7-2 (LS)	FS-LS-3701	Engineering systems for northern hardwoods			
FS 3 7-3 (SO)	FS-SO-3701	Engineering systems for intensive forest management			
FS 3 7-4 (PNW)	FS-PNW-3701	Engineering systems for heavy timber stands in the Pacific Northwest and Alaska			
E8-FS-9		Factors affecting the impregnability of wood		Helsinki, Finland Helsinki, Finland Helsinki, Finland Helsinki, Finland Lima, Peru	IV, A-2-k IV, A-5-h IV, A-4-h IV, A-4-h IV, A-1-g
E8-FS-10		Moisture-temperature-time-strength relations etc.			
E8-FS-18		Accessibility studies of cellulose fiber			
E8-FS-39		Aerobic bacterial degradation of lignin			
S8-FS-1		Collection of wood samples etc. from forest trees of Peru			

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CPO	FS					
FS 4 1	FS 4 1	FOREST SURVEY				V
FS 4 1-1 (NOR)	FS-NOR-4101	Forest Survey - NOR		Juneau, Alaska		V,A-a
FS 4 1-2 (PNW)	FS-PNW-4101	Forest Survey - PNW		Portland, Oregon		V,A-a
FS 4 1-3 (PNW)	FS-PNW-4102	Survey Techniques - PNW		Portland, Oregon		V,A-a
FS 4 1-4 (PSW)	FS-PSW-4101	Forest Survey - PSW		Berkeley, California		V,A-a,d
FS 4 1-5 (INT)	FS-INT-4101	Forest Survey - INT		Ogden, Utah		V,A-a,c
FS 4 1-6 (LS)	FS-LS-4101	Forest Survey - LS		St. Paul, Minnesota		V,A-a,e,g
FS 4 1-7 (NE)	FS-NE-4101	Forest Survey - NE		Upper Darby, Pennsylvania		V,A-a,h
FS 4 1-8 (SO)	FS-SO-4101	Forest Survey - SO		New Orleans, Louisiana		V,A-a,b,f
FS 4 1-9 (SE)	FS-SE-4101	Forest Survey - SE		Asheville, N. Carolina		V,A-a,h
FS 4 1-10 (WO)	FS-WO-4101	Survey Techniques - WO		Washington, D. C.		V,A-h
		Public Law 480 Projects				
E8-FS-30		Increment forecast methods for a large forest area		Helsinki, Finland		V,A-i
E8-FS-32		Improved forest survey methods		Helsinki, Finland		V,A-i
E8-FS-40		Regional comparisons between the actual cuttings, cutting plans, growth, and forest resources. Theory, interpretation and analysis of selected countries		Helsinki, Finland		V,A-i

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FS 4 2	FS 4 2	FOREST ECONOMICS		V
FS 4 2-1 (PNW)	FS-PNW-4201	Production Economics - PNW	Portland, Oregon	
FS 4 2-2 (PNW)	FS-PNW-4202	Multiple-Use - PNW	Portland, Oregon	
FS 4 2-4 (PSW)	FS-PSW-4201	Production Economics - PSW	Berkeley, California	
FS 4 2-5 (PSW)	FS-PSW-4202	Multiple-Use - PSW	Berkeley, California	
FS 4 2-7 (INT)	FS-INT-4201	Production Economics - INT	Ogden, Utah	V, B-e
FS 4 2-8 (INT)	FS-INT-4202	Multiple-Use - INT	Ogden, Utah	
FS 4 2-9 (RM)	FS-RM-4201	Watershed Economics - RM	Flagstaff, Arizona	V, B-f
FS 4 2-11 (LS)	FS-LS-4201	Production Economics - LS	Grand Rapids, Minnesota	
FS 4 2-12 (LS)	FS-LS-4202	Small Woodland Ownerships - LS	St. Paul, Minnesota	
FS 4 2-13 (CS)	FS-CS-4201	Production Economics - CS	Columbus, Ohio	V, B-d
FS 4 2-14 (CS)	FS-CS-4202	Small Woodland Ownerships - CS	Columbus, Ohio	
FS 4 2-15 (SO)	FS-SO-4201	Production Economics - SO	Columbus, Ohio	
FS 4 2-16 (SO)	FS-SO-4202	Small Woodland Ownerships - SO	New Orleans, Louisiana	V, B-b
FS 4 2-18 (NE)	FS-NE-4201	Production Economics - NE	New Orleans, Louisiana	V, B-e
FS 4 2-19 (NE)	FS-NE-4202	Small Woodland Ownerships - NE	Upper Darby, Pennsylvania	
FS 4 2-22 (SE)	FS-SE-4201	Production Economics - SE	Upper Darby, Pennsylvania	
FS 4 2-25 (WO)	FS-WO-4202	Forest Finance - WO	Asheville, N. Carolina	
			Washington, D. C.	
FS 4 3	FS 4 3	FOREST PRODUCTS MARKETING		V
FS 4 3-1 (PNW)	FS-PNW-4301	Marketing - PNW	Portland, Oregon	
FS 4 3-2 (PSW)	FS-PSW-4301	Marketing - PSW	Berkeley, California	
FS 4 3-3 (INT)	FS-INT-4301	Marketing - INT	Ogden, Utah	
FS 4 3-4 (RM)	FS-RM-4301	Marketing - RM	Fort Collins, Colorado	V, C-h
FS 4 3-5 (LS)	FS-LS-4301	Marketing - LS	Duluth, Minnesota	
FS 4 3-6 (CS)	FS-CS-4301	Marketing Practices - CS	Berea, Kentucky	
FS 4 3-7 (CS)	FS-CS-4302	Marketing Development - CS	Carbondale, Illinois	
FS 4 3-8 (SO)	FS-SO-4301	Marketing - SO	New Orleans, Louisiana	V, C-c,d,g
FS 4 3-9 (NE)	FS-NE-4301	Marketing - NE	Upper Darby, Pennsylvania	
FS 4 3-10 (NE)	FS-NE-4302	Marketing Development - NE	S. West Virginia	
FS 4 3-11 (SE)	FS-SE-4301	Marketing - SE	Asheville, N. Carolina	V, C-a,b,e,f,i
FS 4 3-13 (WO)	FS-WO-4301	Requirements - WO	Washington, D. C.	